THE EFFECT OF ROAD CAMBER ON RUNNING KINEMATICS

Donald H Sussman, PhD[1], Martha Walker, MS, PT[2], Michael Tamburello, PhD[2], Bonnie VanLunen, PhD[1], Elizabeth A Dowling, PhD[1], Rachel Atkinson[3], Elizabeth Koss[3], Meghan Mulholland[3], Kelly VanSchoyck[3]
[1]Exercise Science Program, [2]Program in Physical Therapy, [3]Physical Therapy Student, Old Dominion University

Camber, or the crown of roads used for drainage purposes, has been implicated as a cause of overuse injuries, including iliotibial band syndrome, in runners. The purpose of this investigation was to study the effects of varying degrees of simulated road camber and different running velocities on lower extremity kinematics. Using three-dimensional motion analysis, bilateral hip, knee, and ankle angles of 5 injury-free recreational runners were investigated. Subjects were videotaped while running on level and variable cambered surfaces at 6.0 and 7.0 mph. Post-hoc analysis found significant differences between right and left limbs between the right knee at toe off condition 1, 7.0 mph compared to right knee at toe off condition 2, 7.0 mph ($p \leq .004$). Even with this small sample size, it appears that further investigation is required with larger sample sizes.

KEY WORDS: camber, lower extremity, kinematics, running

INTRODUCTION: Millions of Americans choose running as their primary form of physical activity. Unfortunately, more than half of runners will experience some form of injury annually that will cause them to limit their activity (Fabio, 1999). These injuries include tendonitis, especially of the achilles and posterior tibialis tendons, knee pain, foot and ankle problems such as plantar fasciitis and heel spurs, and overuse syndromes such as iliotibial band (ITB) syndrome (Mary, 1992, Magee, 1997, Messier et al., 1995, Ting, 1991 and Gehlsen et al., 1988). This band, which functions as a knee stabilizer, slides forward and backward over the femoral condyle during knee flexion and extension. Excessive rubbing of the band over the lateral condyle during activities such as running produces pain and inflammation (Orchard et al., 1996). Camber, or the crown roads have for drainage purposes, has been implicated as a cause of overuse injuries, including ITB syndrome. Running continually on one side of the road places uneven strains on the legs and can alter lower extremity kinematics leading to injury (Magee, 1997, Messier et al., 1995, Gehlsen et al., 1988 and Orchard, Fricker, Abud, & Mason, 1996). The effect of camber on the kinematics of the lower extremities has been the subject of very limited research. Orchard et al. (1996) tried to replicate the symptoms of patients with ITB syndrome by running on a level surface as well as with a 0.5-cm heel raise inserted in the shoe in an attempt to increase knee flexion angles. This mimicked the effects of camber with one side being higher than the other, but no significant differences in the right/left knee angles were found when compared with one another. A retrospective study by Messier et al. (1995) paired injured and noninjured subjects to compare anthropometric and kinetic data. It was stated that running on camber may lead to running injuries. This conclusion was based on the theory that the foot on the high side excessively pronates leading to injury. However, it was found that the number of subjects training on crowned surfaces was roughly equivalent between the two groups and thus could not be deemed a significant determinant in ITB syndrome. Gehlsen et al. (1988) is the only study to date, which has looked at the simulated effects of camber on the lower extremities in healthy pain-free subjects. The study examined the effects of 0, 5, and 10 degrees of lateral inclination on the knee, and found that only 10 degrees had a significant effect during flexion/extension, internal/external rotation, and varus/valgus in swing phase when the two legs were compared to one another.

According to the Virginia Department of Transportation, streets and sidewalks are only sloped between 2 and 5 degrees, with a departmental standard of 2.0833 degrees. At this time, no study has investigated the kinematic effects of applicable degrees of lateral inclination on the hip, knee, and ankle joints. Therefore, the purpose of this study was to investigate the effects of varying degrees of road camber and running velocity on lower extremity kinematics of recreational runners. It was hypothesized that if running velocity remains constant while camber is altered, significant changes in lower extremity kinematics will occur between level and inclined surfaces. These changes will include increased hip and knee flexion of the "uphill" leg, and increased knee extension of the "downhill" leg. It was also hypothesized that if velocity increased while running on a constant camber, significant changes in lower extremity kinematics will occur between running speeds, and will include increased hip and knee flexion bilaterally.

METHODS: Five subjects (2 males and 3 females) volunteered to participate in this study. During initial screening, subjects signed informed consent and completed a medical history as well as a running history. Based on the questionnaire, those included in the study stated they were at least 18 years of age and recreational runners. A recreational runner was operationally defined as an individual who runs 3-15 miles/week. Participants were then subjected to an orthopedic screening, which was routinely completed by one researcher. The orthopedic screening evaluated the lower extremity for ligamentous instability of the knee using varus/valgus stress tests, Lachman's test, and anterior drawer test for the ankle. Other components of the lower extremity evaluation included gross manual muscle testing, active range of motion, true leg length discrepancy testing, tests for muscular flexibility and functional tests (squatting, walking on toes/heels, and hopping on one foot). Subjects were excluded from the study if the screening indicated positive ligamentous instability, evident leg length discrepancies >1 cm, or any existing musculoskeletal injury. Those subjects with a history of ACL repairs/tears were also excluded from the investigation.

Instrumentation: To simulate street running in the direction of traffic, a treadmill and particleboard were utilized. For level running, the treadmill was not modified. The degrees of camber were achieved by placing the varying numbers of particleboard under the front and back left corners of the treadmill. Camber of 2.5 degrees was attained using 2 pieces of particleboard, while 5 degrees of camber required 4 pieces of particleboard.

The 3D data collection set-up consisted of 4 video recorders surrounding the treadmill, 2 of which were in front of the treadmill, and 2 were behind the treadmill. Cameras captured data at a frequency of 60 Hz.

Procedures: Following completion of medical and running histories and the orthopedic screening, subjects were marked using reflective balls. Six bilateral reflective markers were placed on subjects according to the following landmarks: iliac crests, greater trochanters, lateral knee joint lines, lateral malleoli, lateral calcanei, and bases of the fifth metatarsals. The study investigated 3 conditions as follows: condition 1: 0 degrees camber (running 6.0 mph, running 7.0 mph), condition 2: 2.5 degrees camber (running 6.0 mph, running 7.0 mph), and condition 3: 5.0 degrees camber (running 6.0 mph, running 7.0 mph). Prior to running, subjects were recorded for 2 minutes in static stance. The treadmill speed was then gradually increased to 6.0 mph. Subjects ran for a 2-minute warm-up period at the target velocity, and then 50 strides were recorded for the target velocity. Immediately upon completion of the 50 strides, the treadmill velocity was either increased or decreased to the second target running velocity. Again, subjects ran a 2-minute warm up period, and 50 strides were then recorded for the second target velocity. Between the cambered conditions, subjects were allotted a 2-minute rest period. This process was completed until all experimental conditions were completed.

The videotape was then processed through the PEAK Motus2000 motion measurement software system. Five complete gait cycles were captured from each of the 4 cameras by the PEAK Motus2000 software and save as AVI files. These AVI files were then digitized using the PEAK Motus2000 automatic digitizing module. Subsequently, the X-Y coordinates were filtered and splined in order to generate the limb position data required for analysis in this study.

Research design/data analysis: The data collected were statistically analyzed using a 2X3 factorial design, repeated measures ANOVA with a confidence interval set at $p \leq 0.05$. A post hoc t-test with a Bonferroni correction placed the confidence level at $p \leq 0.004$.

RESULTS AND DISCUSSION: A significant ANOVA main effect was found between right (downhill) and left (uphill) limbs for the knee angles at both initial contact and toe off, as well as the ankle angle at toe off. A post-hoc analysis was performed on these significant values to determine if the ANOVA values were indeed significantly different using a paired t-test with a Bonferroni correction. Due to the number of dependent variables being measured, this lowered the confidence level to $p \leq .004$. After the post-hoc test was completed, the only significant differences were displayed between the right (136.00 ± 10.73^0) and left (151.97 ± 7.12^0) knees at toe off 2.5 degrees camber, 7 mph, and between the right (124.70 ± 16.38^0) and left (155.50 ± 3.43^0) knees at toe off 5 degrees camber, 7 mph. It should be noted that the main effects of the ANOVA showed significant changes for the knee at initial contact and toe off and the ankle at toe off at 2.5 degrees of lateral inclination at 7.0 mph between uphill and downhill limbs. There were several important observed trends in the data. These trends included greater mean values of knee flexion at initial contact and toe off for the uphill leg and greater mean values of knee extension for the downhill leg at all conditions and velocities. The knee kinematics of both the lower extremities were altered when the velocity increased from 6.0 mph to 7.0 mph, with all conditions resulting in greater knee extension. The downhill leg exhibited greater knee extension compared to the uphill leg. The ankle showed greater mean values of plantar flexion as the level of inclination increased. There were no trends that showed altered ankle kinematics as the velocity was changed with camber held constant. Further examination of the data reveals that the hip joint did not show any consistent kinematic changes with changes in camber or velocity. Joint angles between the uphill limb and downhill limb also failed to show any trends. Previous research by Gehlsen, et al. (1988) found similar kinematic changes in their data while running on a camber of 10 degrees. It was believed that more significant changes would have been found in the current study if a larger sample size had been used. The findings of this study may implicate other structures not investigated, such as subtalar joint motion. Gehlsen, et al. (1988) stated that kinematic changes at a 5-degree camber may not have been found because of involvement of the subtalar joint. The subtalar joint axis changes it's orientation throughout the stance phase of gait, alternating between supination and pronation (Nawoczenski, Saltzman & Cook, 1998 and Donatelli, 1996). Normal subtalar joint motion is ten degrees of pronation and twenty degrees of supination passively (Donatelli, 1996). However, during normal gait, the subtalar joint should only deviate a few degrees from neutral into supination and pronation. Anything larger than this could implicate a compensation by other biomechanical factors (Donatelli, 1996). Gehlsen, et al. (1988) stated that the uphill leg would be pronated and the downhill leg supinated to compensate for the camber causing the knee joint to move into a valgus position on the pronated uphill lower limb. It was hypothesized that the subtalar joint was able to compensate for smaller amounts of lateral inclination but at larger degrees of inclination, such as 10 degrees, it would be unable to compensate (Gehlsen et al., 1988). Stergiou, Bates & James (1999) stated that a lack of coordination between the subtalar joint and knee joint actions might result in running related injuries. Their study revealed that as running velocity increased, the rearfoot joint angle was altered resulting in a lateral deviation of the tibia. The trends in the results of the current study suggest if further research is completed, utilizing more subjects that the subtalar joint would not be able to compensate completely for 5 degrees of camber. However, neither study investigated the subtalar motions of supination and pronation to determine if, in fact, the subtalar joint is implicated, or if it is implicated in combination with other factors.

Running produces a large force across the hip, knee, and ankle (Nordin, 1989). If this force is aligned unevenly in any plane, it may cause degeneration of the hip, knee, and/or ankle on one side more than the other. This may be implicated in soft tissue damage such as muscle strains, ligamentous sprains, tendonitis, and bursitis secondary to changes in kinematics. Further research might include examination of supination and pronation of the subtalar joint as a function of increased road camber. The spine, head, and upper extremities might be investigated for changes in kinematics, as well as the effects of patients with leg length discrepancy utilizing the longer extremity for the downhill leg.

CONCLUSIONS: The purpose of this study was to determine if lower extremity kinematics were altered while running on a cambered surface. Fabio (1999) estimated that only 20% of sport medicine treatments are based on scientific evidence. It is important for physical therapists and athletic trainers to base their treatment protocols on research based evidence. This study helped bring scientific backing to running related evaluations and treatments. It is necessary to understand the biomechanics of the lower extremity while running on a crowned surface to determine if road camber should be implicated as a possible cause of the runner's injuries. It is also important to understand that if this is a possible cause, it maybe corrected with a changes in training patterns which do not include a laterally inclined surface, or a running program which incorporates running on both sides of a cambered roadway.

REFERENCES:

Donatelli R. (1996). *The Biomechanics of the Foot and Ankle 2nd ed.* Philadelphia: F.A. Davis Company.

Fabio D. (1999) Myth of evidence-based practice. *Journal of Orthopedic Sports Physical Therapy*, **29**, 632-633.

Gehlsen, Gale M., Stewart, Lawrence B., Van Nelson, C. & Bratz, Janelle S. Knee Kinematics: the Effects of Running on Cambers. *Medicine and Science in Sports and Exercise.* **21**: 463-466, 1988.

Magee, David J. *Orthopedic Physical Assessment, 3rd ed.* (1997). Philadelphia: W.B. Saunders Company, pp 603-605.

Messier, Stephen P., Edwards, David G., Martin, David F., et al (1995). Etiology of Iliotibial Band Friction Syndrome in Distance Runners. *Medicine and Science in Sports and Exercise*, **27**, 951-960.

Nawoczenski D, Saltzman C, Cook T. (1998). The effect of foot structure on the three-dimensional kinematic coupling behavior of the leg and rear foot. *Physical Therapy*, **78**, 404-416.

Nordin M, Fankel V. (1989). *Basic Biomechanics of the Musculoskeletal System 2nd ed.* Lippincott, Williams & Wilkins.

Orchard, John W., Fricker, Peter A., Abud, Anna T, & Mason, Bruce R (1996). Biomechanics of Iliotibial Band Friction Syndrome in Runners. *American Journal of Sports Medicine.* **24**: 375-379.

Stergiou N, Bates B, and James S. (1999). Asynchrony between subtalar and knee joint function during running. *Medicine and Science in Sports and Exercise*, **31**,1645-1655.

Ting, Arthur J. (1991). Running and the Older Adult. *Clinics in Sports Medicine,* **10,** 319-325.