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JOINT LOADING AND MUSCLE ACTIVITY IN THE LOWER BODY WHILE WALKING ON BALLAST

SUMMARY

The kind of surfaces we walk on affects the joint loading in the knees, hips, and ankles as well as the muscle activity patterns around those joints. In other words, torques (also called “moments”) at the hips, knees, and ankles change as we walk on different surfaces. Muscle activity is also altered. This is the general conclusion found by a recent study examining the biomechanics of walking on common railroad yard surfaces. Subjects were found to slow down to walk on mainline ballast (MB), and joint moment ranges were generally smaller if the subjects walked on MB or walking ballast (WB) instead of a level firm surface (no ballast–NB). Muscles in the legs were more actively co-contracting when walking on ballast, presumably to stabilize the joints while navigating uneven or rocky surfaces.

This study was a collaboration between university and industry researchers (Wade, Redfern, Andres, and Breloff, 2010), with data collected at the University of Mississippi. The project was a follow-up to a pilot project (Andres, Holt, and Kubo, 2005) that found rearfoot motion (side-to-side motion of the ankle joint looked at from the rear) increased by 58 percent if subjects walked on MB instead of NB, whereas rearfoot motion did not significantly differ between WB and NB. The pilot project supported a policy of placing WB in locations where railroad employees must walk as part of their jobs. The Wade et al. (2010) study extended the findings beyond the ankles to the hips and knees as well.

Figure 1. Trainmen Walking on Mainline Ballast in a Yard.

Twenty healthy adult men walked along three different pathways (NB, WB, MB) while full-body motion, ground reaction forces, and electromyographic (EMG) signals were collected from the lower extremity muscles. Three-dimensional joint moments were calculated, and moment trajectory ranges, muscle activity (measured by EMG), and temporal gait measures were investigated. The conclusion reached was that walking on ballast increases muscle activation to control the loading or stress at the joints of the lower extremities. Even with a slower, more cautious gait on MB, larger moment profiles occurred compared with WB, and greater co-contraction occurred compared with WB and NB. The current results suggest that increased efforts to place WB where walking occurs and to maintain those surfaces will increase safety and decrease demands on the musculoskeletal systems of railroad employees.

BACKGROUND

Although railroad ballast material provides support and drainage for track structures, the effect on railroad workers who have to walk and work on ballast is not known. The Federal Railroad Administration (FRA) found that walking contributed to 13.9–16.5 percent of all railroad worker injuries and accounted for 16.7–20.3 percent of the days lost from work between 1999 and 2008. Slip, trip, and fall injuries attributed to walking on irregular surfaces accounted for 3.1–5.1 percent of all injuries and up to 5.9 percent of days lost from work during the same period. FRA also found that 35 percent of all reported injuries in 2008 were due to strains or sprains of the back or lower extremities. The question is whether there is a potential link between walking surface characteristics and injury. The type and size of ballast used in railroad yards are believed to affect workers and the way they walk. Railroad managers identified "improper ballast" as a factor that contributed to injuries in railroad yards; they stated that "distribution of smaller 'walking' stone on switch leads instead of the larger ballast rock" might help reduce railroad yard injuries (FRA, 2001).

Railroad workers also identified MB used in the yard as a problem, so FRA suggested several best practices to improve the safety climate and reduce injuries, including the use of "walking stone on switch leads and tow paths."

OBJECTIVES

This study was designed to examine the effect of two common sizes of railroad ballast on gait. The terrain was designed to simulate a railroad work setting to investigate the variation in joint stress and muscle activation while walking on the respective surfaces.

METHODS

Twenty healthy male subjects volunteered and were selected to fit into five anthropometric blocks ranging from the 5th to 95th percentiles in height and weight. Written informed consent was obtained prior to participation.

Participants wore the same brand and model of steel-toed boots. Ballast of different sizes was obtained from a quarry that supplies ballast for railroads in the South and Midwest. The ballast walking surfaces were 8.5 meters (m) long, 1.5 m wide, and 4 inches deep. Full body motions were acquired by a 6-camera system recording 3-D motion from 39 reflective markers placed on the boots and body. Bilateral ground reaction forces were acquired by two force plates embedded in the walkway.

EMG electrodes were placed on the dominant leg muscles. After calibrating the EMGs to maximum voluntary contraction, the participants walked along the walkway repeatedly until 25 successful trials were recorded. Subjects had at least 72 hours between sessions on each of the MB, WB, and NB surfaces.

Figure 2. Markers and EMG Electrodes on the Rear Side of a Subject.

Data processing involved determining heel contact and toe-off from the force platform data for gait cycle normalization. Muscle activation was determined from the integrated EMG normalized to maximum voluntary contraction. A co-contraction index was calculated for agonist-antagonist muscle pairs.

Moment trajectories for each joint were calculated for each trial in each of three planes, time-normalized to a step (heel contact to toe-off), and normalized by the participant's body mass. Normalized moment trajectories were ensemble-averaged within each condition for each subject. Data were subjected to multivariate analyses of repeated measures and corrected for multiple comparisons.

RESULTS

Temporal Gait Parameters—These are timing and distance descriptors for gait. They were significantly different across surfaces and for MB compared with both WB and NB, but WB parameters differed from NB for only a subset of parameters.

Cadence (steps per minute) was significantly less for MB compared with WB and NB, but WB and NB cadences were not statistically different. Stride length was shorter for MB and WB compared with NB, with MB stride length less than WB. Speed was slower for MB compared with WB and NB conditions. Stance and swing duration and double-and single-support duration were longer for MB and WB compared with NB and greater for MB than WB conditions.

Joint Loading Parameters—Hip moments for abduction/adduction were reduced on ballast compared with NB; hip internal/external moments tended to be reduced on ballast also. Knee moments followed this same general pattern except for frontal plane moments being more varus[1] in the NB condition.

Ankle moments were greater in eversion[2] on MB and WB compared with NB. The moment ranges across MB and WB were significantly different for all but one joint plane, and for the hip and knee, the ranges were lower than the NB condition. Only ankle inversion/eversion ranges were different, with the range being greater for MB and WB compared with the NB condition. The ballast conditions result in a greater hip adduction moment, opposite in direction from the NB condition.

EMG Parameters—EMG data recorded from all muscles during the step were generally greater for the MB and WB compared with the NB condition. Mean and peak muscle activities were significantly affected by ballast condition for all lower extremity muscles and were greatest for MB and least for NB.

Burst duration significantly increased progressively from NB to WB to MB. Co-contraction was found in the three agonist/antagonist pairs tested and increased from NB to WB to MB during all phases of the step.

CONCLUSIONS

The goal of this investigation was to study gait during walking on ballast surfaces to better understand the biomechanics and varying movement strategies during locomotion on this irregular surface. Muscle co-contraction is amplified during two primary conditions: when an individual experiences insecurity in a compulsory task and during anticipation of compensatory forces. Individuals also use co-contraction to perform activities with demands that are higher relative to their capability.

Participants in this study slowed down and took shorter steps on the ballast surfaces, reflecting a more cautious gait. Despite these adjustments, participants actually increased the co-contraction around the lower extremity joints to further stabilize the joints.

[1] A deformity in which the distal part of a limb is turned inward toward the midline of the body (dictionary.com).
[2] Turned outward or inside out (dictionary.com).

Although this co-contraction seen during the ballast conditions may improve joint stability in response to difficulty walking, higher joint compression and increased muscle fatigue may also be occurring.

In summary, it appears that walking on railroad ballast increases muscle activation to control the loading on the joints of the lower extremity, potentially increasing both localized muscle fatigue and the compressive force on those joints. Walking on WB compared with walking on MB decreases the joint moments and the muscle co-contraction, making WB a better walkway surface than MB for railroad employees.

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