INCREASING RUNNING STEP RATE REDUCES PATELLOFEMORAL JOINT FORCES

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INTRODUCTION

Anterior knee pain is a common ailment among runners, thought to be triggered in part by the repetitive compressive stress between the patella and femur. The patellofemoral (PF) compressive joint force has been estimated to reach 5.6-7.6 times body weight during running [1,2]. Since PF joint force is influenced by both quadriceps loading and knee flexion angle [3,4], strategies to modulate these parameters may decrease PF compressive forces and ameliorate pain. A recent study showed that a subtle increase in step rate can reduce peak knee flexion and the internal knee extension moment during the loading response phase of running [5]. The purpose of this study was to use computational musculoskeletal models to investigate how step rate modulation affects PF joint loading. We hypothesized that an increase in step rate would reduce PF joint forces, arising from the coupled effect of a reduced knee extension moment and knee flexion angle during stance.

METHODS

We measured whole body kinematics and foot-floor reactions during treadmill running in 23 healthy, experienced runners (14 males, mean ± SD: age = 37.0 ± 14.7 yr, mass = 69.8 ± 9.2 kg, height = 177.6 ± 9.9 cm, 5+ months experience, run 44.6 ± 23.2 km/wk). Each subject ran at his/her preferred running speed under three cadence conditions: 90%, 100% and 110% of preferred step rate. Step rate was maintained via an auditory metronome and confirmed by ground reaction forces.

Joint forces were analyzed using a lower extremity model with 44 muscles acting about the hip, knee and ankle joints [6]. The model was adapted to include a 1-degree of freedom PF joint, in which the patella could translate along a constrained path relative to the femur. Quadriceps muscle and patellar tendon forces were applied to the proximal and distal ends of the patella, respectively. For each subject, the model was first scaled to subject-specific segment lengths. Inverse kinematics was then used to compute the joint angles at each frame of the running motions. Patella position along the constrained path was set assuming the patellar tendon remained a constant length [6]. We then used numerical optimization ($min\sum V_i\bar{F}_i^2$, V=volume) to compute the lower extremity patellar tendon and muscle forces (F_i) necessary to generate the measured joint angle accelerations at each frame of the motion. The magnitude of the PF joint reaction force vector was then computed, with peak PF force averaged over five strides for each step rate. The effect of step rate on peak PF joint force was investigated using paired t-tests with $p<0.05$ establishing significance.

RESULTS AND DISCUSSION

Peak PF joint force occurred during the loading response of stance, with a second smaller peak seen during swing limb initiation (Figure 1). Step rate and PF joint force were inversely related for all subjects, with the lowest PF joint forces observed at the highest step rates (Figure 1).

PF joint forces reached a magnitude of 5.1 (±0.9) times body weight at a preferred step rate (Figure 2). Decreasing step rate increased PF joint force by an average (±SD) of 17.3% (±9.4), while increasing step rate decreased PF joint force by 15.4% (±7.4) ($p<0.05$). These percent changes exceed the previously observed change in knee extension moment seen with the same step rate manipulation [5]. The additional benefit is likely derived from running with a more extended limb at a higher step rate. These runners exhibited a 3.5 deg decrease in knee flexion at the higher step rate [5].

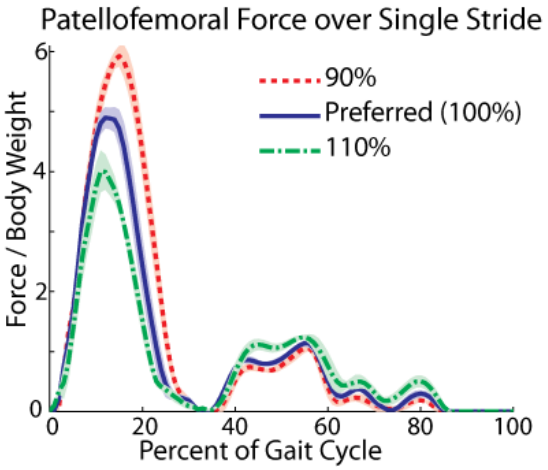

Figure 1: Average (± 1 SD) patellofemoral joint force for a subject running at a decreased (90%), preferred (100%), and increased (110%) step rate.

CONCLUSIONS

Running places high compressive forces on the PF joint, which is likely a contributor to anterior knee pain syndrome commonly observed in distance runners. This study demonstrates that a simple running form modification (i.e. increasing step rate 10% above one's preferred) can be used to substantially diminish peak PF joint force. This biomechanical benefit appears to be due to two factors: a) the ground reaction force passing closer to the knee and reducing the loading on the quadriceps, and b) a more extended knee posture at midstance resulting in a less obtuse angle between the quadriceps and patellar tendons (Figure 3). Therefore, increasing step rate is an effective way to decrease patellofemoral joint forces, and may prove to be a useful, simple strategy for addressing anterior knee pain issues in distance runners.

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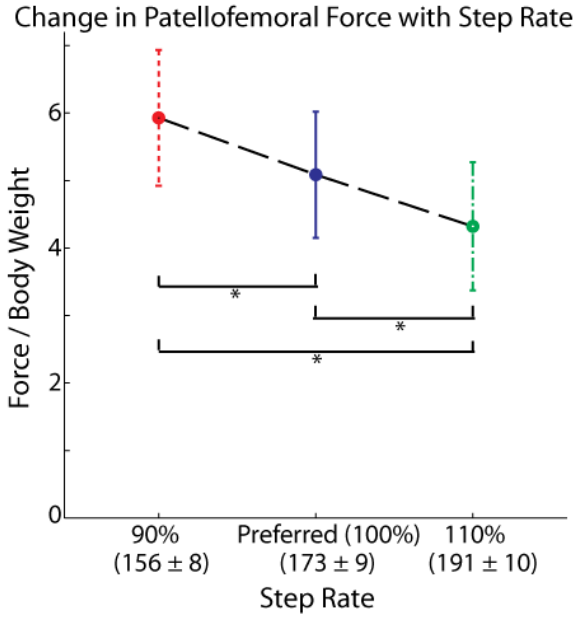

Figure 2: Patellofemoral joint force is inversely related to step rate (mean ± 1SD step rate is shown, *p<0.05)

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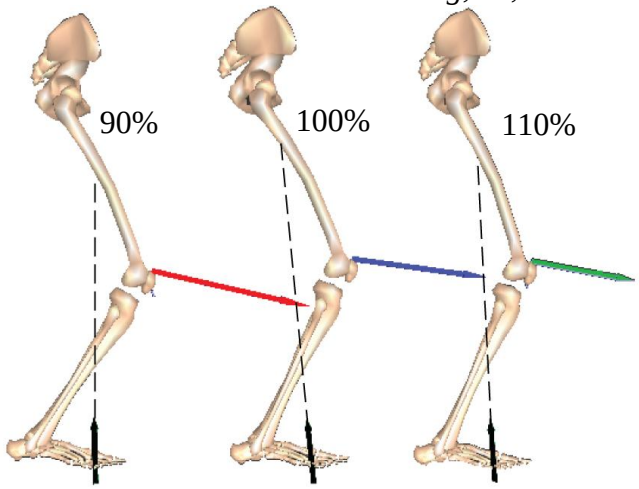

Figure 3: Representative depiction of limb position, ground reactions and peak PF joint force at the 90%, preferred, and 110% step rate conditions.