Peak Knee Joint Contact Force Increases with Body Borne Load During Run-to-Stop Task

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INTRODUCTION

Musculoskeletal injury, particularly of the lower extremity, is a serious military issue that increasingly leads to long-term disability and discharge of the soldier [1]. These injuries often result from repetitive forces that impact the lower limbs during military-relevant tasks, such as the run-to-stop (RTS). Performing the RTS requires rapid deceleration which potentially places large compressive forces on the knee. These compressive forces may further increase with the addition of body borne loads commonly worn during military training, e.g., 20 kg or greater, and potentially lead to musculoskeletal injury. However, to date, the effect of body borne load on knee joint contact force during the RTS is unknown. Unexpected stops, i.e., performing an unplanned, reactive RTS, may further elevate these compressive forces and the subsequent risk of musculoskeletal injury. Therefore, the purpose of this study was to determine if peak knee joint contact force (PKJCF) increases with the addition of body borne load during anticipated and unanticipated RTS tasks.

METHODS

Seven males (21.7 ± 4.2 years; 1.8 ± 0.1 m; 71.7 ± 9.1 kg) had lower limb biomechanical data recorded during a series of RTS maneuvers. Each participant performed the RTS with three military-relevant body borne loads: no load (NL; 6.2 kg), fighting load (FL; 20.0 kg) and approach load (AL; 40.0 kg). While wearing each load, participants performed three anticipated (AN) and unanticipated (UN) RTS maneuvers with their dominant limb. Each RTS required the participant to run at 3.5 m/s ± 5% on a walkway, plant their dominant limb on a force platform (AMTI) embedded in the floor, and immediately stop in a low-ready position. For the AN maneuver, each participant responded to a visual stimulus delivered ~5 s prior to initiation of the movement. During the UN task, each participant responded to a visual stimulus triggered ~600 ms prior to force platform contact.

For each RTS maneuver, sagittal plane limb biomechanics were quantified from the 3D coordinates of 36 reflective skin markers recorded using twelve high-speed (240 Hz) optical cameras (Qualysis AB). The marker trajectories were low-pass filtered with a fourth-order Butterworth filter (12 Hz) by Visual 3D (C-Motion). Biomechanical data (kinematics, kinetics and GRF) were imported into OpenSim [2] to estimate lower limb joint moments, segment positions and muscle forces. The force estimation process entailed generation of an anthropometrically scaled subject-specific model, residual reduction analysis and static optimization. The FL configuration was modeled with a 20 kg point mass applied at the torso center of mass, while the AL included the FL mass and an additional 20 kg attached to the posterior torso. PKJCF was estimated using the Joint Reaction tool and was defined as the force acting on the tibial plateau parallel to the longitudinal tibial axis [3]. Limb stiffness (k) was defined as the ratio of peak vertical ground reaction force (vGRF) to change in leg length (ΔL) [4].

For analysis, PKJCF, peak vGRF, knee flexion moment at PKJCF, ΔL, and k were assessed during the stopping phase (from initial contact of the dominant limb to contact of the non-dominant limb) of each RTS maneuver. Subject-based means for both the AN and UN maneuvers were calculated. The subject based mean for each dependent variable was submitted to a repeated measures ANOVA to test the main effects of and possible interactions between body borne load (NL, FL and AL) and movement type (AN and UN). Where statistically significant (p<0.05) differences were observed, Bonferroni pairwise comparisons were used.
RESULTS AND DISCUSSION

The biomechanical results of the RTS tasks are presented in Table 1. During the RTS, adding body borne load increased the PKJCF (p<0.001) and the potential for musculoskeletal injury. Specifically, participants exhibited a significant 1.15 N/kg increase in PKJCF with the AL compared to the NL configuration (p=0.006), but a similar increase was not evident compared to the FL (0.54 N/kg; p=0.107), or between the NL and FL configurations (0.61 N/kg; p=0.063).

The increased PKJCF evident with body borne load may stem from a simultaneous increase in vGRF (p=0.002) and knee flexion moment (p=0.025). During the RTS, peak vGRF was significantly greater (0.5 N/kg; p=0.014) during the AL compared to the NL configuration. Yet, similar increases of peak vGRF were not evident between the AL and FL (0.3 N/kg; p=0.114), or between the FL and NL conditions (0.2 N/kg; p=0.156). To prevent musculoskeletal injury, the vGRF needs to be attenuated through lower limb (e.g. knee) joint moments. The fact that participants exhibited significantly larger knee flexion moment with the AL compared to NL (p=0.010), but not compared to the FL (p=1.000), or between the NL and FL configurations (p=0.147), supports this contention. The larger external knee flexion moment, which must be counterbalanced by eccentric quadriceps activation to prevent lower limb collapse, potentially increases compressive force and subsequent injury risk of the knee joint, particularly with the heavy (i.e. 40 kg) body borne load.

To prevent collapse of the lower limb and successfully perform the RTS, participants exhibited a significant increase in \( k \) (p=0.015) with the addition of body borne load. However, after controlling for Type I error, \( k \) was not significantly different (p>0.05) between any of the load configurations, which may be attributed to the fact that \( \Delta L \) did not change (p=0.899) when adding body borne load [3]. As such, future research is warranted to determine if varying \( \Delta L \) (i.e. greater lower limb flexion) while performing military-relevant tasks helps soldiers attenuate the larger compressive forces exhibited on the knee joint with the addition of body borne load.

Performing an unplanned RTS did not further elevate the potential for musculoskeletal injury. Specifically, PKJCF did not significantly differ (p=0.693) between the UN (3.05 N/kg) and AN (2.96 N/kg) maneuvers. The insignificant increase in PKJCF during the UN task may be attributed to the fact that participants failed to exhibit a significant increase of peak vGRF (p=0.280), knee flexion moment (p=0.864), \( k \) (p=0.463), or \( \Delta L \) (p=0.398) as compared to the AN maneuvers.

CONCLUSIONS

The addition of body borne load during military-relevant tasks likely increases the risk of musculoskeletal injury. This elevated risk results from greater compressive force on the knee joint that may be attributed to the increased peak vGRF and knee flexion moment evident with the heavy (40 kg) body borne load. Yet, performing an unplanned task did not result in greater knee joint force and risk of musculoskeletal injury. Future research should determine the lower limb mechanical patterns necessary to decrease the compressive force on the knee joint, particularly with heavy body borne loads.

REFERENCES


Table 1: Biomechanical Results for each Load and Movement Type

<table>
<thead>
<tr>
<th></th>
<th>NL</th>
<th>UN</th>
<th>AN</th>
<th>UN</th>
<th>AN</th>
<th>UN</th>
</tr>
</thead>
<tbody>
<tr>
<td>PKJCF (N/kg)*</td>
<td>2.40 ± 0.41</td>
<td>2.44 ± 0.60</td>
<td>2.91 ± 0.46</td>
<td>3.14 ± 0.71</td>
<td>3.58 ± 0.62</td>
<td>3.56 ± 0.47</td>
</tr>
<tr>
<td>vGRF (N/kg)*</td>
<td>1.72 ± 0.42</td>
<td>1.82 ± 0.45</td>
<td>2.01 ± 0.38</td>
<td>2.08 ± 0.39</td>
<td>2.31 ± 0.39</td>
<td>2.31 ± 0.19</td>
</tr>
<tr>
<td>Knee Moment (Nm/kg)*</td>
<td>2.06 ± 1.19</td>
<td>1.35 ± 1.67</td>
<td>2.55 ± 1.70</td>
<td>2.54 ± 2.08</td>
<td>2.98 ± 1.36</td>
<td>3.33 ± 2.86</td>
</tr>
<tr>
<td>( k )*</td>
<td>10.30 ± 4.59</td>
<td>10.56 ± 3.98</td>
<td>10.02 ± 3.82</td>
<td>11.40 ± 2.94</td>
<td>12.36 ± 1.43</td>
<td>13.00 ± 2.17</td>
</tr>
<tr>
<td>( \Delta L ) (m)</td>
<td>0.20 ± 0.05</td>
<td>0.21 ± 0.05</td>
<td>0.21 ± 0.03</td>
<td>0.21 ± 0.03</td>
<td>0.21 ± 0.03</td>
<td>0.20 ± 0.03</td>
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*significant (p<0.05) effect of body borne load