# LOAD CARRIAGE ALTERS TIBIOFEMORAL KINEMATICS DURING SLOW JOGGING IN ADULT MEN AND WOMEN

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The purpose of this investigation was to determine the effects of load carriage on tibiofemoral kinematics during running. Nineteen healthy, recreationally active adults completed dynamic biplane radiography trials of the dominant limb knee with no load (BW), and an additional 55% of body weight (+55%BW) while running 10% above gait transition velocity. A volumetric model-based tracking technique was utilized to derive medial translation excursion, proximal (inferior-superior) translation excursion, anterior translation excursion, flexion, internal rotation and abduction. At heel strike, running with +55%BW exhibited a more flexed knee compared to BW. However, BW exhibited more proximal translation excursion compared to +55%BW. By contrast, +55%BW had greater anterior translation excursion compared to BW. There were no significant differences between BW and +55%BW for medial translation excursion, internal rotation angle/excursion or abduction angle/excursion The greater knee flexion angle at heel strike for +55%BW may serve as a mechanism to better attenuate the greater impact force via eccentric muscle action. However, reduced proximal translation excursion during +55%BW could suggest greater loading of the soft tissues.

**KEYWORDS:** Gait, Kinematics, Knee, Load Carriage, Musculoskeletal Injury

**INTRODUCTION:** Adventure, ultra-distance, and obstacle course races are characterized by components of load carriage (e.g. rucksacks or weight vests) that mimic common military tasks (Birat et al., 2020; Sherrier and Onishi 2019). Some events have observed up to 70% of the competitors suffering an injury (Borland and Rogers 1997). About 24% of all observed injuries are musculoskeletal injuries (MSI) that affect the lower extremity (Hawley et al., 2017; Mclaughlin et al., 2006; Rabb and Coleby, 2018), with the knee accounting for the majority of lower extremity MSI observed (Hawley et al., 2017; Rabb and Coleby, 2018). In conjunction with injuries sustained during races, about 67% individuals report MSI in the days following the race, mostly attributed to the lower extremity (Borland and Rogers 1997). While the source of MSI during these events is unknown, observed high incidence of MSI during load carriage in military populations (Jensen et al., 2019) suggests load carriage components of races as a potential culprit. In recent years these races have observed a significant increase in popularity amongst general outdoor enthusiasts (Birat et al., 2020; Sherrier and Onishi 2019), suggesting the need to better understand tibiofemoral kinematics under load in males and females. *In vivo* tibiofemoral kinematics via biplane radiography provide the most accurate internal joint data (within 0.2mm & 1° of error) (Anderst et al., 2009; Pitcairn et al., 2018). The higher resolution data acquisition provides invaluable insight to the specific bone segment kinematics, especially in the frontal and transverse plane which is often linked to the development of MSI (Asay et al., 2017). Load carriage research has been predominantly measured by retroreflective marker-based motion capture systems, which are prone to significant error (13.0mm & 4.4° [Benoit et al., 2006]), and are unable to measure the internal joint dynamics. Moreover, women are underrepresented in the load carriage literature (Loverro et al., 2019). Thus, there is a need for investigations of a mixed sex sample that utilizes the gold standard measurement technology (biplane radiography). To that end, the purpose of this investigation was to determine the effects of load carriage on tibiofemoral kinematics during slow running in healthy young adults, which mimics the pace of running observed. It was hypothesized 1) that load carriage would increase flexion, abduction and internal rotation angle at heel-strike, 2) as well as total joint excursion in those planes of motion, and 3) load carriage would increase medial, proximal and anterior translation excursion during initial stance phase.

**METHODS:** Nineteen healthy and recreationally active young adults (11 male: 24.6±4.0yrs, 1.80±0.08m, 78.9kg; 8 female: 27.0±3.7yrs, 1.64±0.05m, 61.0±11.4kg) completed six total trials of running with and without load. All participants were informed of the risks and provided written consent prior to participation. Procedures: Biplane radiography (150 Hz) was used to measure tibiofemoral kinematics in the dominant limb knee for a single stride (refer to Figure 1) with no load (BW), and an additional 55% of body weight (+55%BW). Load carriage was achieved with a plate carrier and weight vest. All participants were provided with boots to standardize footwear. Prior to data collection trials, gait transition velocity (GTV) was determined as the mean GTV of 3 walk-to-run trials utilizing a ramped treadmill protocol. Mean GTV was obtained for each load condition separately. All experimental trials (three for each load condition) were executed at a velocity 10% above mean GTV for ~30 seconds. Data Reduction: Dynamic imaging data was reduced with a volumetric model-based tracking technique was utilized to match the model position to the bone position within an individual frame of the radiograph (Anderst et al., 2009) (see Figure 1). Stride data was then interpolated to 101 data points to represent percent of stance phase. Heel strike was identified as the first instance vGRF exceeded 50N. Excursion was calculated from heel strike through the initial stance phase; first 18% of stance phase was used due to greatest impact forces occurring during this portion and to ensure cleanest imaging for all participants within the capture window. Medial translation excursion, proximal (inferior-superior) translation excursion, anterior translation excursion, flexion, internal rotation and abduction were the derived outcomes.

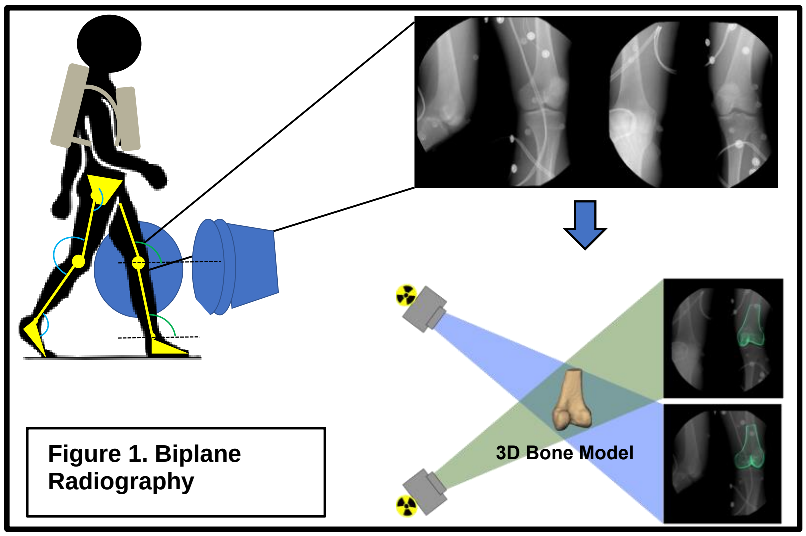


**Figure 1. Biplane Radiography**

Statistical Analysis: Mean and standard deviations were calculated for all outcomes. To determine the effects of load carriage on tibiofemoral kinematics paired t-tests were conducted on medial translation, proximal translation, anterior translation, flexion, internal rotation and abduction at heel-strike and total excursion separately. Cohen d's effect sizes were calculated for each comparison to indicate magnitude of effect with d≤0.2 representing a small effect, d=0.21-0.79 representing a medium effect and d>0.8 representing a large effect. Alpha set to p≤0.05.

**RESULTS:** Mean trial velocity was 1.70±0.22 m/s and 1.57±0.25 m/s for unloaded and loaded respectively. Refer to Table 1 for mean, standard deviation, p-values and effect sizes of all outcomes and comparisons between loads. At heel strike, running with +55%BW exhibited a more flexed knee (p=.01, d=0.42) compared to BW. However, BW and +55%BW exhibited relatively similar flexion excursion. BW exhibited more proximal translation excursion (p=.01, d=0.48) through the first 18% of stance compared to +55%BW. By contrast, +55%BW had greater anterior translation excursion (p<.01, d=0.47) compared to BW. There were no significant differences between BW and +55%BW for medial translation excursion, internal rotation angle/excursion or abduction angle/excursion (see Table 1).

**Table 1. Tibiofemoral Kinematics**

| Variable | | BW | +55%BW | p value | Cohen's d |
|---|---|---|---|---|---|
| Medial Translation (mm) | Excursion | 0.74±0.25 | 0.79±0.44 | 0.66 | 0.14 |
| Proximal Translation (mm) | Excursion* | 2.95±1.23 | 2.40±1.05 | 0.01 | 0.48 |
| Anterior Translation (mm) | Excursion* | 3.84±2.53 | 5.07±2.62 | <0.01 | 0.47 |
| Flexion (°) | Heel-Strike* | 160.43±12.29 | 154.02±18.12 | 0.01 | 0.42 |
| | Excursion | 21.01±10.93 | 20.05±10.47 | 0.27 | 0.09 |
| Internal Rotation (°) | Heel-Strike | -2.70±11.81 | -3.39±12.96 | 0.72 | 0.06 |
| | Excursion | 2.67±5.58 | 3.04±5.81 | 0.71 | 0.07 |
| Abduction (°) | Heel-Strike | -2.80±4.36 | -1.71±5.23 | 0.24 | 0.23 |
| | Excursion | 7.28±2.41 | 7.58±2.32 | 0.46 | 0.13 |

**DISCUSSION:** This is one of the first investigations to examine tibiofemoral kinematics comparing running unloaded and loaded in men and women. *In vivo* tibiofemoral kinematics via dynamic biplane radiography is a highly accurate measurement of internal joint data with a standard error of measurement of 0.2mm for translation and 1° for rotation (Anderst et al., 2009; Pitcairn et al., 2018). Thus, results derived from these measurement techniques can be interpreted with greater veracity. The only change potentially related to MSI included the increased proximal (superior-inferior) translation excursion. Interestingly, internal rotation and abduction was not significantly different between +55%BW and BW, failing to support part of our hypothesis. Supporting previous research (Dever et al., 2021), load carriage increased knee flexion by ~4° at the point of initial contact (i.e., heel-strike) (see Table 1). The greater knee flexion angle at heel strike for +55%BW may serve as a mechanism to optimally align the lower extremity to better attenuate the greater impact force via eccentric muscle action (Farley and Ferris, 1998). Moreover, reliance on greater energy absorption through eccentric muscle action can aid in the storage of potential energy (Farley and Ferris, 1998). Despite more flexion at initial contact, flexion excursion was about the same between unloaded and loaded conditions (see Table 1). Therefore, increased knee flexion at heel-strike with load carriage would be a desirable alteration given excursion remains unchanged in order to ameliorate deleterious forces in the tibiofemoral joint. Abduction and internal rotation angle/excursion were not significantly different from BW and +55%BW (see Table 1) failing to support hypothesis 1 and 2. These outcomes are often associated with markers of MSI such as osteoarthritis (Asay et al., 2017), thus the present results could indicate that load carriage is not the mechanism of observed MSI. However, reduced proximal translation excursion during +55%BW could suggest greater loading of the soft tissues which may portend cumulative mechanical stress related MSI of the knee. Therefore, future research should be conducted with a longer trial period to determine effects of task duration, investigate additional outcomes such as joint space, and examine other common tasks utilized during adventure races to better elucidate potential mechanisms of MSI.

**CONCLUSION:** Executing slow jogging with load carriage up to +55%BW significantly changes tibiofemoral kinematics. Increases in knee flexion at heel-strike from unloaded to loaded indicate an appropriate response to the load carriage as it may serve to better attenuate shock forces. Decreased proximal translation excursion warrants further investigation as it may result in greater stress on the soft tissues. Given the lack of changes in frontal and transverse plane tibiofemoral kinematics, the load carriage component of adventure races may not be the primary culprit of high MSI incidence and therefore other activities related to these events should be evaluated to determine potential risks. Nonetheless, caution should be taken by smaller competitors of adventure races where load carriage components of the race represent a more substantial percentage of their bodyweight (i.e., >+55%BW).

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