Changes in Leg Joint Moments in Response to Altered Vertical Limb Loading during Walking in Individuals with Knee Osteoarthritis

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INTRODUCTION: Knee osteoarthritis (KOA) is the most common chronic disability globally, marked by symptoms including pain, perceptions of stiffness, and impaired physical function. Abnormal knee joint mechanics during walking are primary biomechanical contributors to the onset and progression of KOA. Current therapeutic strategies aim to reduce pain and preserve function through strength and mobility training. However, those strategies leave aberrant joint loading during walking uncorrected. Real-time biofeedback during walking provides a direct method to modify gait biomechanics. When targeting a marker of compressive joint loading—such as vertical ground reaction force (vGRF)—this approach has shown therapeutic potential in populations at elevated risk for KOA (e.g., following joint injury) [1]. Specifically, we can intervene to address sustained aberrant compressive loading and encourage more dynamic compressive loading, potentially promoting cartilage integrity. However, it remains unclear how individuals with diagnosed KOA respond to alterations in vGRF cued via real-time biofeedback. In a repeated-measures design, we evaluated the acute effects of biofeedback-guided alterations in peak vGRF (i.e., -3%, +3%, +6%, and +9% of habitual) on hip, knee, and ankle joint moments and their respective step-to-step variabilities in individuals with KOA. We hypothesized that participants would progressively increase their hip, knee, and ankle extensor moments when targeting larger than habitual vGRF targets (+3% to +9%) and decrease these measures when targeting the smaller than habitual vGRF target (-3%). Within-subject differences in the relative extent to which individual joints changed in response to vGRF biofeedback would be interpreted in the context of neuromuscular strategies used to accomplish the walking task. We further hypothesized that step-to-step variability in leg joint moments would progressively increase with vGRF targets that deviated from habitual values—assumed to mirror task difficulty.

METHODS: Ten older adults (5 female) with clinically diagnosed mild-to-moderate knee osteoarthritis have thus far participated. All participants provided written informed consent according to institutional review board approval. Participants completed five treadmill walking trials: the first without real-time biofeedback (habitual walking) and, in randomized order, four biofeedback conditions that cued targets of −3%, +3%, +6%, and +9% of body weight (BW) relative to each participant's habitual peak vGRF. A monitor displayed the target line alongside the step-by-step first peak vGRF from each leg, and participants were instructed to match the target. We collected marker position data at 100 Hz via a 16-camera motion capture system in synchrony with 3D ground reaction forces at 1000 Hz via a dual-belt, instrumented treadmill. Inverse kinematics and kinetics pipelines in OpenSim estimateed hip, knee, and ankle joint moments. From these curves, we calculated step-by-step variabilities in peak joint moments (defined as the standard deviation) and stride-average values for each condition. Linear mixed effects models evaluated main effects of condition, limb, and the condition×limb interaction.

RESULTS SECTION: Participants successfully responded to biofeedback-cued alterations in peak vGRF. Figure 1 shows the resultant changes in peak hip, knee, and ankle joint extensor moments of the leg predominantly impacted by KOA (involved limb). We first found no significant condition×limb interaction, implying that neither KOA nor KOA symptoms affected the ability of participants to modulate lower extremity joint moments when augmenting vGRF with biofeedback. Peak knee extensor moments varied on average as hypothesized, decreasing with lesser vGRF and increasing with greater vGRF; though, these variations have not yet reached statistical significance. Conversely, participants significantly altered their hip extension moment (HEM), though not consistently in the manner hypothesized. Here, all biofeedback targets increased HEM values on average, with ANOVA effects approaching significance ($p = 0.078$), driven primarily by increases for +9 %BW vGRF target condition ($p = 0.020$). We found far more pervasive effects of biofeedback on step-to-step joint moment variabilities (ANOVAs: $p < 0.0001$). Significant condition main effects generally showed that—independent of joint—peak moment variables averaged least for the -3 %BW vGRF condition and most for the +6 %BW and/or +9 %BW vGRF conditions.

DISCUSSION: Individuals with KOA demonstrated the ability to acutely adapt leg joint extensor moments in response to biofeedback designed to alter lower extremity compressive limb loading via real-time monitoring of the vGRF. Importantly, those adaptations were not limb-specific; the more and less affected limbs have thus far demonstrated indistinguishable capacities to accommodate altered limb loading. We interpret this outcome to suggest that, despite mild-to-moderate joint disease, KOA does not prevent the deployment of new neuromuscular strategies that may be required during gait retraining. We also learned that—perhaps not surprisingly—prescribing changes in vGRF known to positively affect knee cartilage biology simultaneously compels people with KOA to augment their hip joint kinetics. Thus, a more comprehensive biomechanical analysis is warranted to fully understand its therapeutic efficacy. Consistent with a target-based motor control task (i.e., vGRF biofeedback), step-to-step variability increased for all leg joint moments with targets eliciting larger than habitual vGRF values. We believe this reflects: (i) increased task difficulty, (ii) the prescient need for step-to-step corrections, and/or (iii) an increase in the number of neuromuscular strategies available to accomplish the same task. Moreover, the current limitations on sample size and acute study design restrict generalizability, underscoring the need for ongoing and future work to better establish therapeutic relevance.

SIGNIFICANCE/CLINICAL RELEVANCE: This project addresses the gap in understanding how individuals with KOA modify lower extremity joint moments in response to biofeedback-guided modifications designed to augment compressive limb loading in walking. Our findings support the feasibility of deploying targeted biofeedback to modify aberrant limb loading in KOA, underscore the need for biomechanical evaluations beyond the knee, and suggest that KOA or its symptoms do not appear to affect one's ability to modulate lower extremity joint moments when augmenting vGRF with biofeedback.

REFERENCES: [1] Bjornsen et al., *J Orthop Res*, 2025.

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