Study Title: Optimization of Hip-exoskeleton Weight Attributes

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Participants

Twenty-one healthy participants (12 males, 9 females, age 26.8 ±5.57 years, body height 172.8 ± 7.58 cm, body weight 65.9 ± 8.53 kg) were recruited for this study. Exclusion criteria included relevant musculoskeletal injuries, abnormal gait deviations, and weight bearing restrictions. Prior to the experiment, participants had their footedness evaluated to ensure that they were right footed. The University of Texas Institutional Review Board approved the experimental protocol and subjects were provided informed written consent.

Experimental setup and protocol

Participants were tasked with traversing a treadmill while bearing scuba weights secured with a diving belt (Scuba Choice, Los Angeles CA). Weights of 4 kg, 6 kg, and 8 kg were suspended on the pelvis in three configurations: weight evenly distributed between both anterior iliac crests (Bilateral, BI), weight on the 4th lumbar vertebrae (Lumbar, L), and weight on the non-dominant left anterior iliac crest (Unilateral, UNI). Fig. 1 illustrates these placements.

We collected Motion capture marker data with a 13-camera motion capture system and 36 active markers attached to the lower body and torso segment (Phase Space, San Leandro, CA). Ground reaction forces (GRF) were measured through force plates in an instrumented split-belt treadmill (Bertec, Columbus, OH). Surface electromyography data (EMG) (Bortec, Calgary, AL) were collected from the rectus femoris (RF), medial hamstring (MH), tibialis anterior (TA), and lateral gastrocnemius (GAS) of each leg.

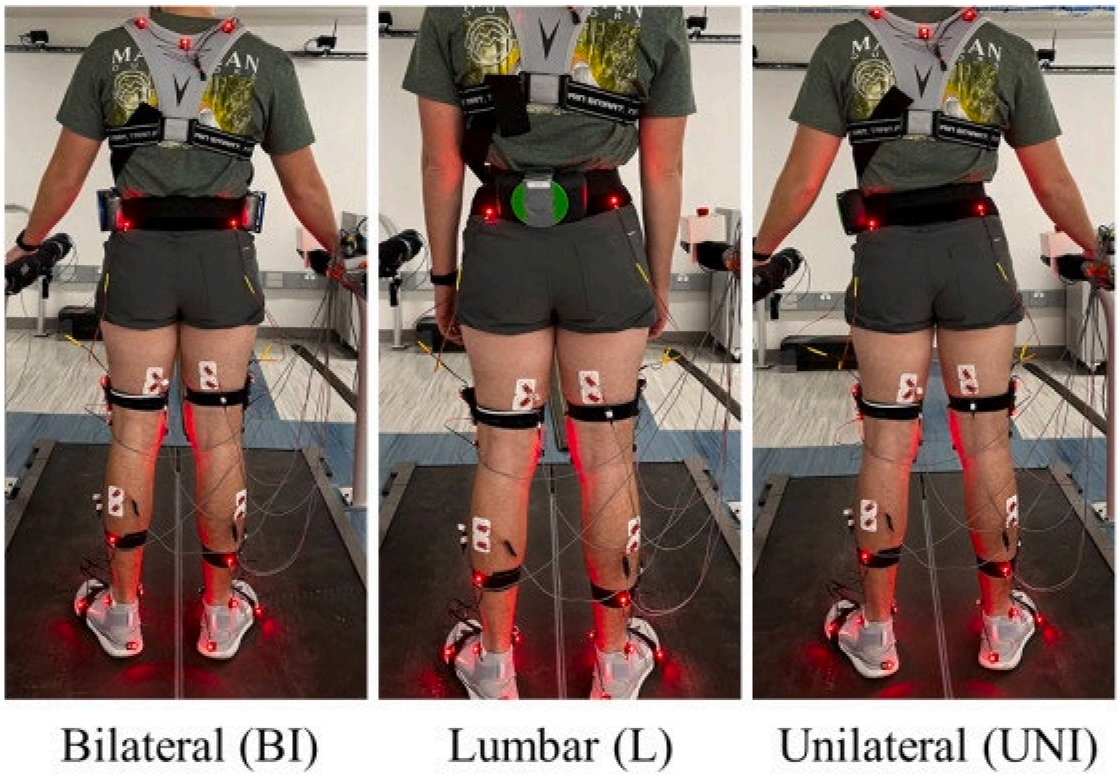

Fig. 1. Weight placements during an experiment. Also shown are the motion capture LEDs, EMG electrodes, and split belt treadmill.

Participants walked for 1m30s at a speed of 1.1 m/s for every combination of weight (4, 6 and 8 kg), placement (BI, UNI, L), and no weight (NW) in pseudo-randomized order. The participants were exposed to each condition two times, for 20 total trials. After every five trials subjects were given a break of 2 min.

Data processing

Using GRFs, we defined heel strike and toe off events, which were then used to identify gait phases. Starting from heel strike, the gait phases were defined as initial stance, mid stance, late stance, and swing, ending the gait cycle with the proceeding heel strike. For each trial, we ignored the first 30 s to account for familiarization to the condition. For outlier detection, we removed an individual stride if the waveform exceeded 2 inter-quartile-ranges from the median waveform for more than 40% of the gait cycle. The mean waveform from the last 30 strides was evaluated.

We recorded all biometric data at 960 Hz. First, all these signals were downsampled to 480 Hz. Force plate data were low-pass filtered with 4th order Butterworth filter at 20 Hz. Motion capture data were low-pass filtered with 4th order Butterworth filter at 6 Hz. Surface EMG signals were processed with a high-pass filter of 40 Hz, demeaned, rectified, and low-pass filtered at 4 Hz. We used motion capture data and GRFs with an open-source musculoskeletal simulation software, OpenSim 4.3. We scaled a musculoskeletal model to match the anthropometry of each subject, and then performed inverse kinematics and dynamics for joint angles and moments, respectively.

Outcome measures

We contextualized the joint motion for the hips and knees as Range-of-Motion (ROM), the difference between the maximum and minimum joint angles within a given period. We analyzed the effect of weight on the hip and knee sagittal plane motion during initial stance phase. We quantified pelvic tilt and obliquity as the average position within a gait phase.

EMG signals were normalized via the mean-dynamic method centering the EMG signal around 1. For data analysis, the EMG signal was integrated along each gait phase to calculate the integrated EMG (iEMG) values. We analyzed the RF muscle activation during initial stance and the GAS muscle activation during late stance.

Statistical analysis

R 4.1.1 (2021 The R Foundation for Statistical Computing) was used for statistical analysis. One subject was removed from the dataset due to technical errors with recording the data.

We used a linear mixed regression model (*lme4* 1.1.27.1 and *lmerTest* 3.1.3) with two fixed effects (weight and placement) along with a no weight condition and one random effect (subject) and $\alpha<0.05$. A Tukey Honestly Significant Difference post-hoc test was performed to determine pairwise differences between weights, placements, and their interactive effects.