# Evaluating Smart Insoles to Track and Treat Lower Extremity Overuse Injuries

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## Military Relevance

**Motivation: Musculoskeletal injury (MSKI) of the lower extremities, the most common MSKI site, disrupts training and introduces significant financial cost.**

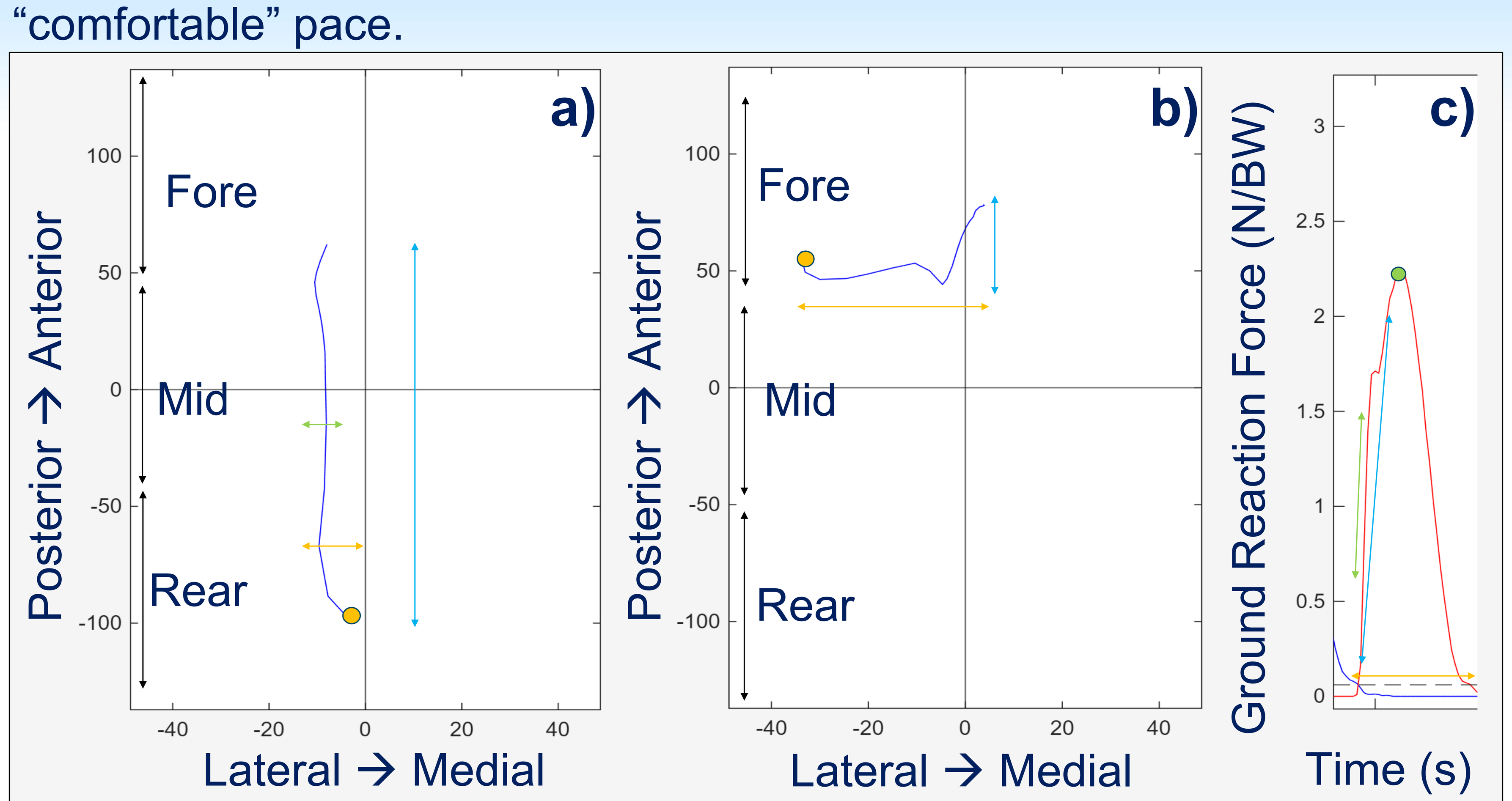
**Hypothesis: Instrumented insoles can be used during routine physical training to identify gait patterns associated with increased rates of MSKI.**

**Opportunity**: Instrumented insoles containing accelerometers and an array of pressure sensors can monitor gait mechanics outside of a lab during training activities. Analysis of the data can provide several metrics associated with injury in the literature, including:

- Force: peak force[1], average loading rate (ALR)[2], maximum instantaneous loading rate (ILR)[2], impulse[1]
- Center-of-pressure (COP): location of initial anterior-posterior (AP) COP[3], initial mediolateral (ML) COP variability[4], AP excursion[2], lateral to medial ML excursion length[5,6,7]
- Time: Ground contact time (GCT)[2]
- Symmetry: Asymmetry index[8]; <15% typically classifies "healthy"[9]

## Study Overview

**Methods**: 17 midshipmen (9M, 8F; ages 18-23) at the United States Naval Academy participated in an outdoor 1-mile run at a self-selected "comfortable" pace.




**a) Rearfoot strike** measures shown are initial AP/ML COP (yellow ●), rearfoot ML excursion (yellow ↔), midfoot ML excursion (green ↔), AP excursion (blue ↕)
**b) Forefoot strike** measures shown are initial AP/ML COP (yellow ●), ML excursion (yellow ↔), AP excursion (blue ↕)
**c) Ground reaction force** measures shown are peak force (green ●), ALR (blue ↕), ILR (green ↕), GCT (yellow ↔), impulse (area under the curve)

**1) Insole Collection**

16 pressure sensors and a 6-axis IMU were used to extract temporal, spatial, force, and pressure-based gait features in addition to asymmetries.

**2) Feature Extraction**

Algorithm extracts 1) Force metrics and normalizes them to bodyweight (BW) 2) COP metrics and places them on a length/width normalized axis 3) Asymmetry quantified by the Symmetry Index (SI).[10]

**3) Statistical Analysis**

1) Linear mixed effects model (LMEM) (Fixed: Speed, Limb, Height, Sex; Random: Subject) to adjust means for covariate effects; utilizes Z-score to detect outliers (Z > 2) respective to strike pattern.

2) Spearman's rank correlation coefficient for correlation over time.

## Results

**No injuries were reported in our population during this event; however, published risk indicators were observed in some participants:**

- Rearfoot strikers may have twice the injury incidence of forefoot strikers[3]: 13 participants
- Forefoot strikers are more susceptible to Achilles injuries[3]: 1 participant
- Low AP excursion is a risk factor for Achilles tendinopathy[2]: 1 participant
- Asymmetry is a risk indicator: 1 participant demonstrated >15% asymmetry for 3 metrics
- Certain participants changed their strike pattern over time without change in ground contact time (proxy for speed), as shown in Table 1. Strike pattern shifts may indicate fatigue.

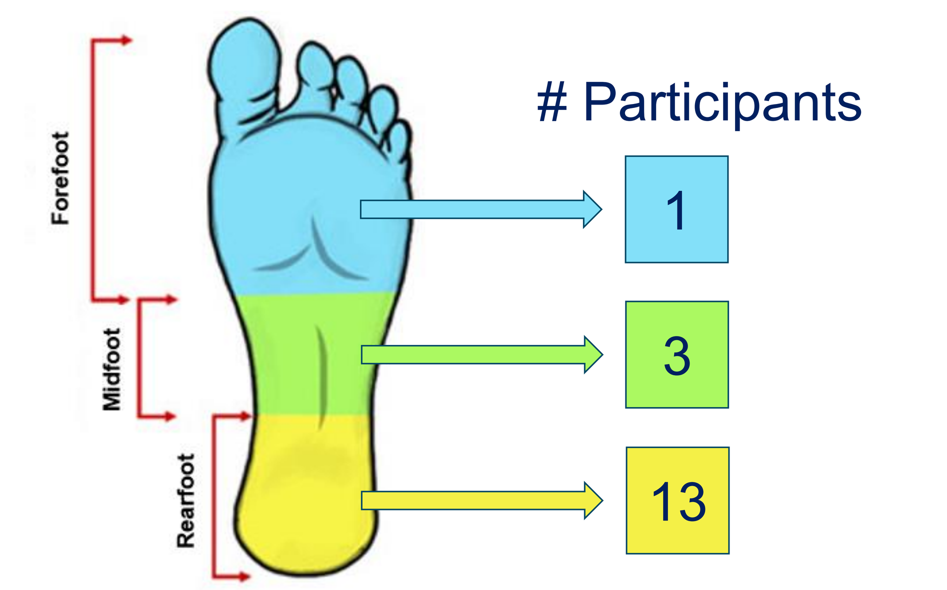



Figure 1. Cohort strike pattern demographics as classified by average initial AP COP

Table 1. Strike Pattern Shifts Over Time

| Strike Pattern Shift | Correlation | Participant |
|---|---|---|
| Bilateral Anterior | 0.4 to 0.7 | 2 |
| Bilateral Anterior | 0.7 to 1.0 | 1 |
| Unilateral Anterior | 0.4 to 0.7 | 3 |
| Unilateral Posterior | -0.7 to -1.0 | 1 |

Individual strike pattern changes over run as classified by Spearman's correlation coefficient

Table 2. Identified Participant Risk Factors

| Metric | Participants w/ Risk Factor | Participants w/ Symmetry Index > 15% |
|---|---|---|
| Peak Force (N/BW) | 0 | 1 |
| ALR (N/BW-s) | 1 | 7 |
| ILR (N/BW-s) | 0 | 9 |
| Impulse (N-s/BW) | 0 | 1 |
| GCT (s) | 1 | 0 |
| Initial ML COP Variability | 1 | N/A |
| AP Excursion | 1 | N/A |

Participants identified to have risk factor for MSKI relative to the rest of study population as classified by adjusted mean (adjusted with LMEM model results) greater than 2 standard deviations (Z>2) from the population mean

## Next Steps

**In an upcoming stage of the study, we will:**

1. Seek to identify whether collected gait metrics correlate with injury in individuals training for marathons (i.e., engaging in a high volume, high MSKI risk activity).
2. Determine user and clinician acceptance of a smart insole-based risk management system.

**Conclusions** Instrumented insoles can track features of gait that are documented in literature to correlate with MSKI risk, as well as identify biomechanical differences between and within individuals in a field setting.

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