WEDGED FOOTWEAR PERTURBATIONS AFFECT LOWER EXTREMITY COORDINATION DYNAMICS

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The purpose of this study was to investigate the coordinative changes that occur with a footwear perturbation consisting of a neutral shoe and varus and valgus wedged shoes. This type of footwear is often prescribed for clinical use. Lower extremity kinematics were collected as six male subjects ran overground at 3.6 $m \cdot s^{-1}$±5%. A modified vector coding technique assessed coordination between rearfoot motion and leg rotation. It was determined that there were clinically relevant differences between the footwear during the middle and late stance period. The differences were most evident between the varus and valgus conditions. However, the varus condition was closer in coordination structure to the neutral condition. The difference in coordination during the wedged conditions indicated that the valgus wedge perturbation may have implications in producing soft tissue injury.

KEY WORDS: coordination, vector coding, wedged shoes, running

INTRODUCTION: Wedged shoes, orthotics and insoles are commonly prescribed to runners and clinical populations to treat injury or pathology in the lower extremity. Altering rearfoot motion can adjust the kinematics farther up the chain in the limb (Bates et al., 1978). Examining the coordinated motion of the lower extremity segments in space and time gives insights that traditional time series plots of segment motion cannot. The purpose of this study was to examine how a wedged shoe intervention influenced coordination patterns between the rearfoot and leg. We hypothesized that the varus and valgus wedged footwear would result in coordinative patterns that were significantly different from each other and both would be different from the neutral shoe.

METHODS: Six healthy male subjects participated in this study. The mean age, height and body mass of the subjects was 31.2±4.9 years years, 177.3±5.99 cm and 77.2±10.3 kg respectively. All subjects gave written, informed consent to participate in the study, were injury-free and had normal values for pronation during walking and running. Subjects wore custom shoes with sole wedges made of EVA. Neutral, 8° varus and 8° valgus shoe wedges ran the entire length of the sole (see Figure 1).

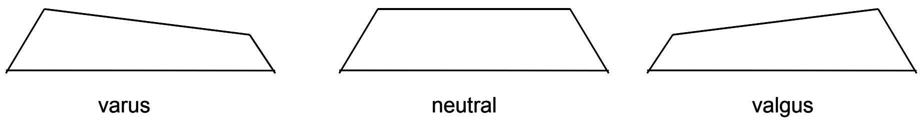

Figure 1: Illustration of shoe sole wedges for the right shoe from a posterior view.

Lower extremity kinematics were captured (240 Hz) as subjects ran overground across a force platform (1200 Hz) at 3.6 $m \cdot s^{-1}$±5%. Five trials were collected in each shoe condition. The vertical ground reaction force component was used to identify heel contact and toe-off. Kinematic data were low-pass filtered (8 Hz) and interpolated to 101 data points in Visual 3D. Rearfoot eversion/inversion and leg internal/external rotation segment angles were calculated in the global coordinate system and scaled relative to the standing posture.

A modified vector coding approach assessed the coordination between the segments. Angle-angle plots of the leg (*x*) relative to the rearfoot (*y*) were constructed. Inter-segment coordination was inferred from the vector angle (θ_i) between adjacent points relative to the right horizontal (Sparrow et al., 1987; Heiderscheit et al., 2002).

$$\theta_i = \left| \tan^{-1} \frac{(y_{i+1} - y_i)}{(x_{i+1} - x_i)} \right|, \text{ where } \theta_i \text{ is the coupling angle}$$

Due to the directional nature of the vector angles, each trial's coupling angles were calculated from the mean horizontal and vertical components during each 1% of stance and averaged using circular statistics (Batschelet, 1981). Angles were grouped into bins to identify the range of specific coordinative patterns the segments could undergo (Table 1).

Table 1: Coordination patterns defined by coupling angle ranges

Coordination pattern	Coupling angle definitions	
Proximal	157.5° < γ ≤ 202.5°	337.5° < γ ≤ 22.5°
Distal	67.5° < γ ≤ 112.5°	247.5° < γ ≤ 292.5°
In-phase	22. 5° < γ ≤ 67.5°	202.5° < γ ≤ 247.5°
Anti-phase	112.5° < γ ≤ 157.5°	292.5° < γ ≤ 337.5°

Vector angles classified as in-phase indicated the same degree of rearfoot eversion rotation as leg internal rotation. Anti-phase coordination indicated the same amount of opposing rotations of rearfoot eversion/inversion with leg external/internal rotation. Distal coordination indicated rearfoot motion relative to a stationary leg segment and proximal indicates leg rotation relative to a stationary rearfoot segment (Figure 2).

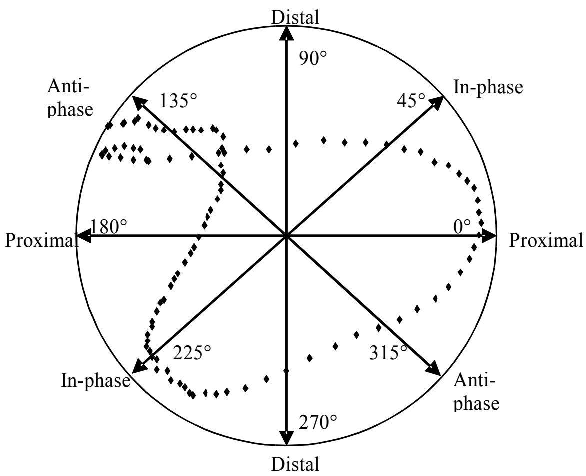

Figure 2: An exemplar angle-angle plot of hip and knee joint motion during the stance phase of a single trial. A polar plot is overlaid to illustrate the four different coordinative patterns.

Circular statistics were used to calculate mean coupling angles during each third of stance (Batschelet, 1981) and effect sizes assessed differences between coordination patterns in the three shoe conditions (Cohen, 1991).

RESULTS and DISCUSSION: The purpose of this study was to examine coordinative patterns between the rearfoot and leg as a result of a wedged shoe perturbation. Rearfoot segment angles (Figure 3) resulted in greater differences than leg angle among the conditions. For example, the valgus wedge had lesser peak eversion, when referenced to a standing position, than the varus wedge. The valgus wedge also had greater range of rearfoot motion than the neutral or varus wedge.

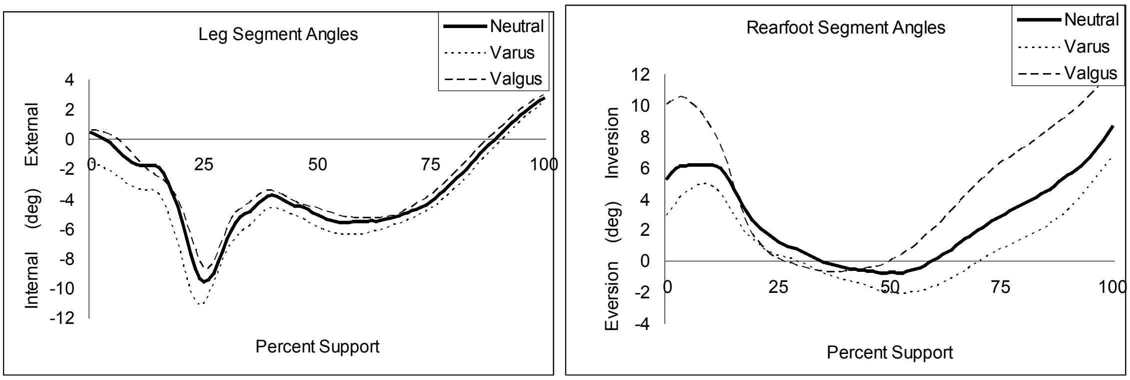

Figure 3: Ensemble averages of leg and rearfoot segment angles across stance.

A vector coding approach assessed four different coordination patterns during the stance phase of running. Coordination patterns differed between the three shoe conditions with the valgus wedge having a greater impact on the coordination dynamics then the varus wedge. Figure 4 shows the mean coupling angles from heel stride to toe-off.

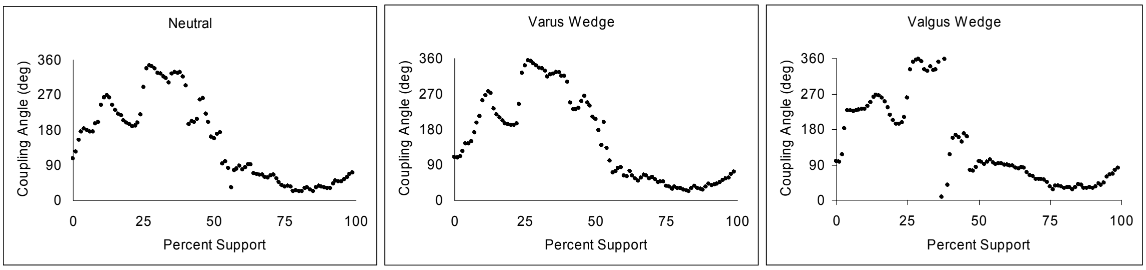

Figure 4: Ensemble mean coupling angles during the stance phase of running.

On heel-strike, a brief period of distal coordination predominated when the rearfoot everted relative to a stationary leg segment. This lasted until the foot was flat on the running surface. Subsequently, the segments shifted towards more in-phase pattern as the rearfoot began to evert while the leg internally rotated. For a brief period during early-mid stance, the leg was externally rotated while the rearfoot continued to evert; thus an anti-phase coordination is shown at approximately 25% of stance. At toe-off, the rearfoot inverted closely followed by leg external rotation; in-phase coordination is shown during the last 50% of stance. The differences between the two wedged insole conditions was particularly pronounced during mid and late stance. Coupling angles during early, mid and late stance are presented in Table 2.

The coordination was in-phase during early stance. During mid-stance, proximal segment coordination predominated in the neutral and varus wedged shoes, but a mean anti-phase coordination was present in the valgus wedge, suggesting opposing rotations of the two segments. During late stance, the segments were in-phase as the leg externally rotated with rearfoot inversion. The valgus wedge imposed a greater perturbation to the lower extremity rearfoot-leg dynamics than the varus wedge, particularly in mid and late stance.

Table 2: Mean vector coding angles across tertiles of stance. Numbers indicate differences from other shoe conditions. Neutral = 1; Varus wedge = 2; Valgus wedge = 3. Plain text numbers indicate an effect size of 0.5 or higher, suggesting a moderate effect of shoe condition. Bold numbers indicate an effect size of 0.7 or higher, suggesting a large effect of shoe condition.

	Early Stance	Mid Stance	Late Stance
Neutral (1)	231.2°	180.6°	42.7° **[3]**
Varus (2)	232.1°	190.9° [3]	42.4° [3]
Valgus (3)	242.3°	136.9° [2]	45.7° **[1,2]**

During mid-stance, there was a difference in the timing of the initiation of rearfoot inversion between the varus and valgus wedged shoes. There was, however, no difference in timing of initiation of leg external rotation.

CONCLUSIONS: Despite the same degree of perturbation through wedging, a valgus wedge had a greater impact on the rearfoot-leg coordination than a varus wedge. These differences were greatest in the latter portions of stance. The differences in rearfoot range of motion in late stance and lack of differences in leg range of motion among the three shoe conditions accounts for the differences in coordination just prior to toe-off. The opposing rotations shown during mid-stance in the valgus wedge may have important implications for soft-tissue or ligament injury at the ankle joint or in other joints of the lower extremity.

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