INTRODUCTION
Coordination is foundational to human movement⁴. One prominent model of coordination is the Haken-Kelso-Bunz (HKB) which predicts change in relative phase between two oscillators according to the following equation:

\[ \phi = \Delta \omega - a \sin(\phi) - 2b \sin(2\phi) - \sqrt{Q_\tau}, \]

where \( \Delta \omega \) quantifies differences in natural periods between the oscillators. The ratio, \( b/a \), models the collective frequency of coordinated oscillation. \( \sqrt{Q_\tau} \) is a noise term with strength \( Q \).

\( \Delta \omega \) is an ‘imperfection parameter’ that predicts deviations in relative phase, \( \phi \), due to timing differences in oscillators. Another possibility is that deviations of \( \phi \) might result from asymmetries in spatial alignment of oscillators, such as in visual motor coordination. We propose two possible mechanisms for modeling asymmetry based on a modified HKB model:

\[ \phi = \Delta \omega + \Delta s - a \sin(\phi - \eta) - 2b \sin(2\phi) - \sqrt{Q_\tau}. \]

Two potential terms, \( \Delta s \) and \( \eta \), can model the effects of spatial asymmetries of oscillators. Both predict shifts in mean relative phase, \( \phi \), away from stable fixed points. Only the \( \Delta s \) parameter predicts a shift in \( SD_\phi \), a decrease in the stability of coordination. This study was designed to distinguish which, if either, of those parameters best models spatial asymmetry.

METHODS
10 healthy adults (26.4 ± 6.87 years, 7 males, 3 females) participated in this study. A 6-camera system (Optotrak, NDI) measured upper body movement at 100 Hz. The aim was to investigate the effects of reference frame alignment on the form and stability of visuomotor coordination. Participants coordinated their arm movements with a visually displayed sinusoidally oscillating stimulus (\( S_{\text{Sine}} \)). Forearm movements pivoted about the elbow which rested on a rotating platform. A user controlled visual stimulus (\( S_{\text{RA}} \)) was displayed on the screen that oscillated due to elbow rotation. Figure 1A shows a display in which the horizontal centers of oscillation of \( S_{\text{Sine}} \) and \( S_{\text{RA}} \) are manipulated. Given horizontal screen coordinates (x) an amplitude of oscillation (A) of \( S_{\text{Sine}} \), we scaled this offset parameter as \( \rho = x_{\text{shift}}/A \) (Figure 1C). Figure 1B depicts the relative positions of \( S_{\text{Sine}} \) and \( S_{\text{RA}} \) for \( \rho = -2.0 \) over several cycles. We hypothesized that particular spatial offsets will be preferred. To test this hypothesis, we studied preferences for particular spatial arrangements of \( S_{\text{Sine}} \) and \( S_{\text{RA}} \) that arise from initial arrangements of \( \rho = -3, -2, -1, 0, 1, 2 \) or 3. Participants were free to move the location of \( S_{\text{RA}} \) as long as they could comfortably perform anti-phase and in-phase coordination. Subjects performed 3 trials for each phase (in-phase, anti-phase) \( \times \rho \) pair, each lasting 60 seconds. 3 practice trials were given at \( \rho = 0 \) to familiarize subjects with the task.

Analysis Strategy. We computed instantaneous relative phase between \( S_{\text{Sine}} \) and \( S_{\text{RA}} \) for all trials, along with circular means and standard deviations.³ We then modeled \( \phi \) and \( SD_\phi \) as a function of \( \rho \) and phase (in-phase/antiphase) in separate Bayesian multilevel models developed specifically for circular/directional dependent variables.³

RESULTS AND DISCUSSION
Estimates in Table 1 replicate well known differences between required phases because the 95% credible intervals defined by LB and UB do not overlap. Modeling results in Table 2 show that most slope estimates indicate that a one unit change in \( \rho \) predicts a negative change in \( \phi \) because credible intervals do not contain 0. Models relating \( \rho \) and \( SD_\phi \) (not reported to due to space) found no evidence of such a relationship, implying that \( \Delta s \) may not be useful in modeling asymmetry effects.

CONCLUSIONS
Results suggest that, in the current context, spatial asymmetries may best be modeled via the \( \eta \) parameter in the modified HKB model. Future work will investigate the extent to which this modification transfers to other conditions of asymmetry.

REFERENCES

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