Intention and attention in gestural coordination: Asymmetric HKB model

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To what extent could natural language have evolved from manual gestures? Increasingly, research is indicating that Broca's area is implicated in manual gestures perception as well as articulatory gestures production (Corballis, 2002). We approach speech-hand coordination from a dynamical systems perspective (Tuller & Kelso, 1984) with special interest in how attention and laterality entail stability and function. In particular, the issue of intended vis-à-vis perceived speech-hand synchrony is addressed.

Method

Ten right-handers (RH) and 12 left-handers (LH) synchronised either speech (/ba/-/ba/-/ba/...) or finger tapping with a pacing signal while simultaneously moving the other articulator in either a 1:1 in-phase or anti-phase manner as a metronome was increased in frequency from 1.2 to 2.8 Hz (10 cycles per frequency plateau; 0.1 Hz increments). Participants attended to tapping or speech. Kinematic data from finger and jaw were collected. Using cross-spectral coherence, a mean estimate of relative phase across all frequency plateaus (prior to any phase transition from anti-phase) was used to quantify speech-hand coordination. Continuous relative phase was used to derive standard deviation of relative phase. When the finger lead the jaw, $-180° < \phi < 0°$ (i.e., ϕ negative) and when the jaw lead the finger, $0° < \phi < 180°$ (i.e., ϕ positive). Absolute phase shift and signed phase shift, $\Delta\phi$, yielded information about direction (i.e., undershoot or overshoot) and magnitude of phase departure from the desired pattern.

Results

All ANOVA and post hoc tests as well as results from regressions reported are significant at the $p < 0.05$ level (or less). For in-phase coordination, for both RH and LH, there was a negative average phase shift for both right and the left hand (finger lead over jaw) and it was greater for the right than for the left hand. Thus, both RH and LH groups acted similarly with respect to the right hand. In contrast, for anti-phase coordination, RH and LH performed differently. For RH, their positive phase shift (jaw lead over finger) was of comparable magnitude for the right and the left hand (jaw lead). For LH, there was also a positive phase shift but only for the right hand—for the left hand they exhibited a negative phase shift (finger lead). Thus, anti-phase speech-hand coordination using the left hand distinguished RH from LH.

For in-phase coordination and the left hand, the increase in frequency produced a decrease in negative phase shift and a switch to a positive phase shift and increasingly so (i.e., $\Delta\phi$ changed from undershooting to overshooting 0º) (e.g., see RH in Fig. 1). For the right hand, $\Delta\phi$ undershot 0º. In anti-phase coordination, the increase in frequency resulted in a decrease in positive phase shift and an increase in negative phase shift and increasingly so (i.e., relative phase changed from undershooting 180º to overshooting 180º), for both right and left hands.

********************** Insert Figure 1 about here **********************

The SD(ϕ) was similar for RH and LH and was greater for anti-phase than for in-phase for both the right and the left hand. For in-phase, phase variability was comparable for the right and the left hand for both RH and LH. However, for anti-phase coordination variability was greater for the left than for the right hand in LH. Importantly, phase variability *decreased* with the increase in required frequency (Fig. 1). Although the linear trend was not always significant for anti-phase coordination, the quadratic trend was so for both the right and the left hand of both RH and LH. This may be due to the stabilising factor of attention.

Effects of attention were also revealed in the patterning and degree of absolute phase shift. Although for LH and in-phase coordination there was no difference in the magnitude of phase shift when attention was directed to either speech or tapping, for anti-phase coordination, greater shift was observed when attention was directed to tapping than to speech. Additionally, when attention was on tapping, a greater phase shift was observed for anti-phase coordination than for in-phase. For RH, phase shift also tended to be greater when attention was on tapping than on speech.

Thus, the effects of attention were most pronounced for the less stable anti-phase coordination. Similarly, the aspect of speech-hand coordination that was most “susceptible” to cognitive intervention (via a shift in the attractors for anti-phase) was when tapping was synchronised with the metronome. Our results lend support to the proposal that attention can stabilise and shift the stable states of coordinated perception-action (Riley et al., 1997).

Discussion

The current results on RH and LH can be accommodated by the extended asymmetric HKB model (Treffner & Turvey, 1995) (Equation 1).

$$\dot{\phi} = \Delta\omega - a\sin(\phi + p) - 2b\sin(2\phi + p) - c\cos(\phi + p) - 2d\cos(2\phi + p) + \sqrt{Q}\xi \qquad (1)$$

Figure 2 depicts the evolution of a viable model from origins in the canonical HKB model with assumed noise, increasing pacing frequency (decreasing b/a), and biomechanical finger-jaw eigenfrequency difference, ($\Delta\omega$; Fig. 2A, B), through incorporation of a fixed attention factor (d; Fig. 2C), and *increasing* attention (d_{step}; Fig. 2D), and through incorporation of a constant phase offset or bias (p) that captures the intentional synchrony associated with one’s perception and production of the timing underlying synchronous events (i.e., perceptual- or “p”-centres”; Fig. 2E). The final model (Fig. 2F) incorporates the hitherto unmotivated asymmetric c-term which “pulls and stretches” the profiles of Figure 2E in opposite directions such that the attractors increasingly approach and overshoot $\phi = 180°$, and increasingly undershoot $\phi = 0°/360°$ (cf. data of Fig. 1).

********************** Insert Figure 2 about here **********************

The asymmetric HKB equation with phase-offset (Treffner & Peter, 2002) lends insight into the continually decreasing phase shift (due to increasing attention) as frequency increases, as well as the near-U-shaped SD(ϕ) profiles found by others studying the influence of attention on coordination dynamics (Temprado et al.,1999; Zanone et al., 2001). The regressions of Figure 1 confirm a close correspondence between the frequency at which minimum variability (minimum of U-function) and minimal phase shift ($\Delta\omega$ = 0) occurs. This frequency underlies comfort mode states and corresponds to the cardinal in-phase and anti-phase attractors. Perception-action synchrony during speech-hand coordination evolves according to the asymmetric attentional HKB model—provided an “intentional asynchrony” (phase offset) is incorporated. Perceptual synchrony does not imply actual synchrony, although, *functionally*, synchrony may exist. Importantly, such functional synchrony evolves according to lawful dynamics, and therefore affords gestural coordination and ultimately communication.

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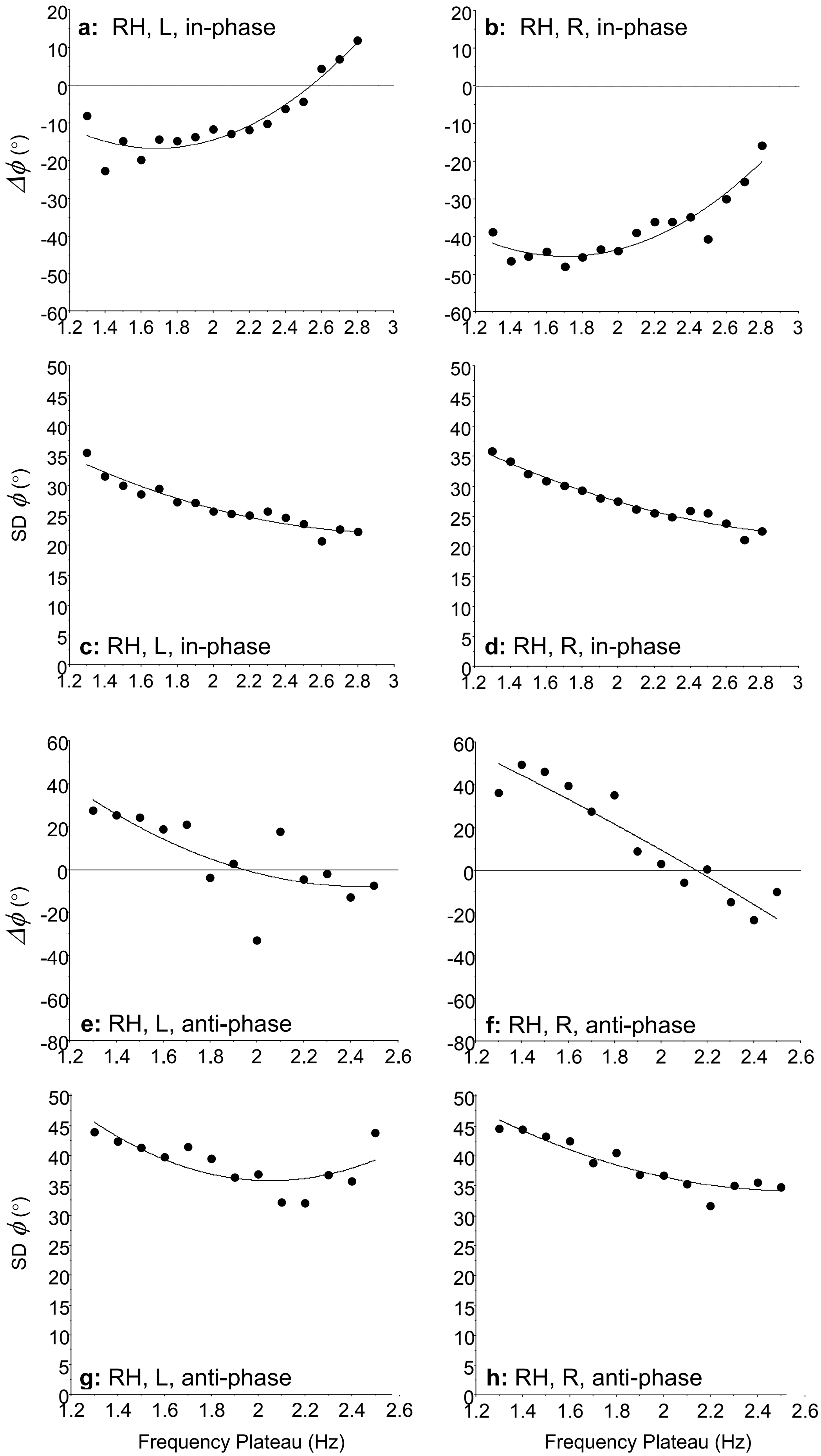
Figure 1.
Effect of frequency, intended phase, and hand (L, R) on phase shift and variability in right-handers (RH).



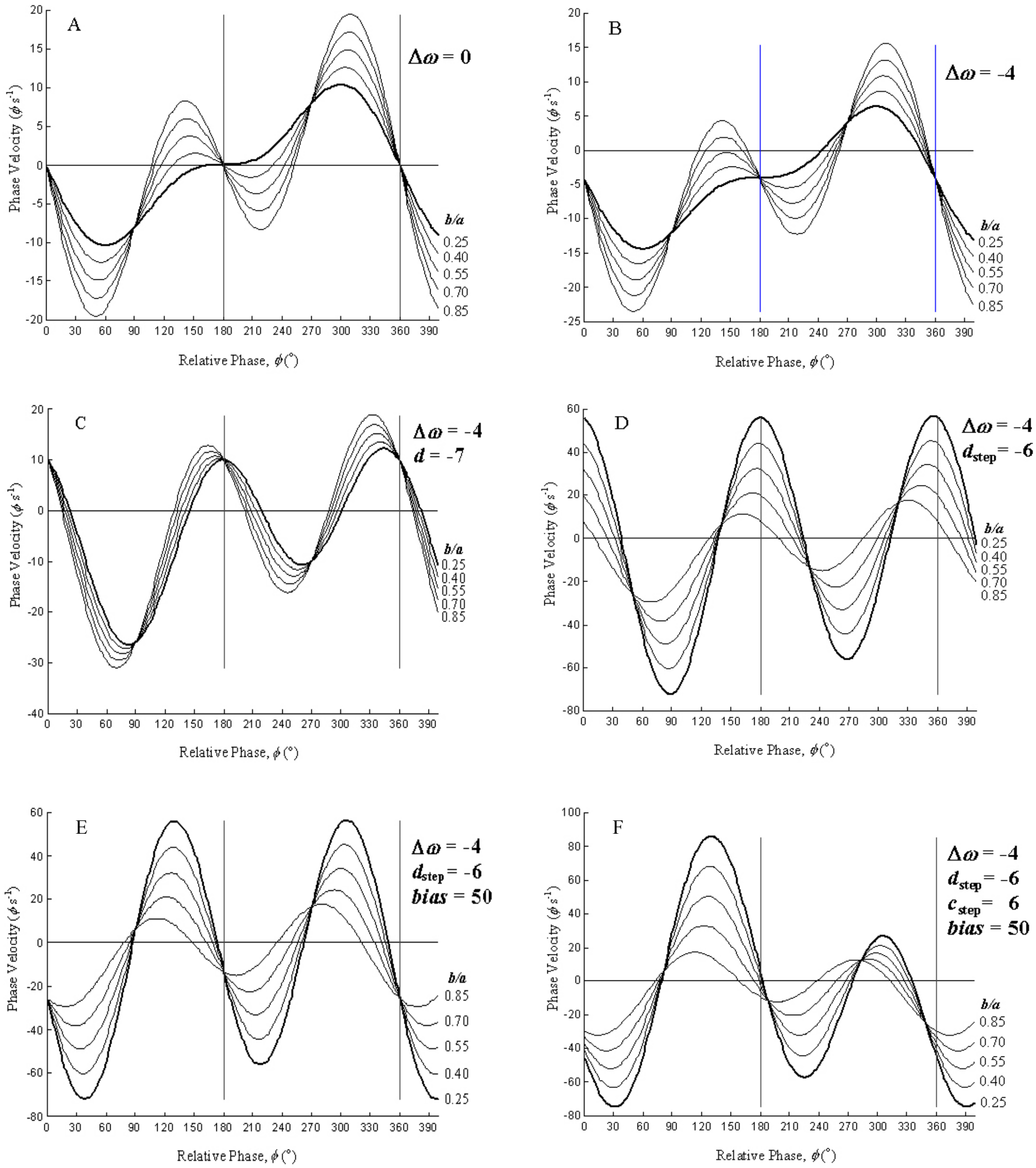


Figure 2.
Evolution of asymmetric HKB equation (see text for details).

Figure 2