The Auditory Coordination Of Between-Person Rhythmic Movements

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Past research has demonstrated how the visual coordination of rhythmic movements between two people (e.g., two people coordinating handheld pendulums) exhibits patterns of coordination that can be explained by dynamical processes of self-organization. This research has shown that two patterns of coordination, inphase and antiphase (0° and 180° relative phase) can easily be maintained though visual coordination. If the difference in the inherent frequencies of the two effectors is increased (by making the handheld pendulums more different in their lengths), the relative phasing of the movements becomes more variable and exhibits a proportional lagging of the inherently slower (larger) effector. These coordinative properties have been modeled by a coupled oscillator dynamic that has steady-state attractors at 0° and 180° relative phase and whose stability can be manipulated by scaling the difference between inherent frequencies of the two oscillators (Schmidt & Turvey, 1994).

The present study will investigate whether this kind of dynamical organization is also established when auditory information links the two coordinating individuals. Although one can think of many cases in which we visually coordinate movements with another person, instances in which we use auditory information to do so are less common. Two individuals performing music together is perhaps one such instance where the hegemony of vision is suppressed and the auditory consequences of Person’s A movements are used by Person B to coordinate his/her movements (and vice versa). The present study reproduces the structure of this natural occurrence in an adaptation of our between-person laboratory task. Of interest is (a) whether the two people will be able to coordinate the swinging of handheld pendulums using only a sound emitted from the bottom of the pendulums; (b) whether there is any evidence of relative phase attractors underlying this auditory coupling; and (c) how strong
the auditory coupling is compared to other kinds of interlimb couplings previously observed.

Method

Pairs of subjects sat in chairs facing the same direction and oscillated hand-held pendulums in the sagittal plane using their outside hand. The pendulums consisted of an ash dowel with a bicycle hand grip attached to the top and a small rectangular metronome attached 3 cm from the bottom. Four pendulums of different lengths were used. Each of the five subject pairs was asked to oscillate isochronously five combinations of the pendulums during the experiment. These pendulum combinations had five different inherent frequency differences or \( \Delta \omega \). Angular excursions of the wrist were collected using electrogoniometers (Penny & Giles, Santa Monica, CA) attached to each subject’s wrists and forearms.

For each trial, the subject pairs were instructed to look straight ahead so that they could not see one another, to swing their pendulums at a comfortable rate, to listen to the 440 Hz tone emitted from the metronome on the other person’s pendulum and use it to coordinate the swinging of the pendulums either in an inphase or an antiphase pattern depending upon the trial. There were a total of ten conditions (2 phase modes \( \times \) 5 pendulum combinations). Each condition was performed twice for a total of twenty 15 s trials.

Results and Discussion

In order to evaluate the auditory interlimb coordination, the continuous relative phase was calculated from the individual wrist angular excursions (Schmidt & Turvey, 1994). As can be seen for a representative antiphase trial in Figure 1, the subjects found the task quite difficult. Phase locking was intermittent for most trials. Consequently, in order to evaluate the coordination, each trial was broken into three 5 s segments creating 300 such segments for the data set. Slightly more than half of the segments (55%) were phase locked. Of these 56% were correct inphase and 44% were correct antiphase phase locking. Interestingly, in a substantial number of the unlocked segments (16%), the coordination was captured momentarily in the alternative incorrect phase mode. These results suggest that auditory information can be used to establish the between-person coordination. However, the phase locking created is unstable and intermittent.

Figure 1. Between-person auditory coordination time series. Note intermittent 0° phase locking at \( * \).

In order to determine whether the stable phase locking observed was produced by an coupled oscillatory strategy, the mean deviation from 0° and 180° (\( \phi \)) and its standard deviation (\( \phi \) SD) were calculated for each stable segment. A significant regression of \( \phi \) on \( \Delta \omega \) (\( \phi^2(161)=17, p < .001 \)) suggests a proportional lagging of the larger pendulum with the difference between the inherent frequencies of the two wrist-pendulums. A significant second order polynomial regression of \( \phi \) SD on \( \Delta \omega \) (\( \phi^2(161)=.04, p < .05 \)) indicates a U-shaped relation between phase fluctuations and the inherent frequency difference of the two wrist-pendulums. These results demonstrate that as two pendulums differed more and more in their length, (a) the larger pendulum tended to follow the shorter one in its cycle and (b) the variability of relative phasing increased. Together they replicate the results found for visual between-person coordination and provide evidence that coupled oscillatory dynamics underlies the auditory between-person coordination.

How does the strength of the auditory coupling compare to that of the between-person visual coupling and the within-person 'neural' coupling of two wrists? Given that the number of unstable segments (55%) is much greater than the number of unstable segments observed in either of these kinds of coordination (4% and 0%, respectively), one expects that the auditory coupling
should be much weaker. Assuming a simple coupled oscillator model, the strength of the coupling $K$ can be estimated through a regression analysis (Schmidt & Turvey, 1995). For the present data, the auditory coupling $K$ was estimated to be 0.13. For visual between-person and within-person coordination, $K$ was estimated for comparable frequencies to be 0.40 and 0.83, respectively (Schmidt, Bienvenu, Fitzpatrick, & Amazeen, in press). Given the weakness of the coupling and the ensuing intermittency, methods developed for the analysis of relative coordination in addition to the steady state analyses performed here may be illuminating.

References


Section III: *Action*

III.B: *Movement and Dynamics*