Effects of Social and Physical Variables on Between-Person Visual Coordination

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Between-person visual coordination of rhythmic limb movements was investigated under manipulation of both social and physical variables. Each member of a pair of participants oscillated a hand-held pendulum at the same tempo, with both visually coordinating their movements so as to maintain the alternate phase mode. Participants' social competence was assessed and they were paired to produce three types of combinations: high-high (HH), low-low (LL), and high-low (HL). The frequency of oscillation (set by a metronome) and the preferred frequency difference of the pendulum combinations (set by changing the relative lengths of the pendulums to be coordinated) were manipulated. Mean relative phase angle $\phi$ and its variability were measured as indices of coordination. Standard results from interlimb coordination were replicated in the manipulation of the physical variables: (a) More breakdowns in phase locking (defined as mean $\phi$s outside the stable $130^\circ$ to $230^\circ$ range) were observed for the higher frequency of oscillation, (b) Relative phase lag changed proportionately with absolute difference in the preferred frequency of the individual pendulums. Further, anomalous $\phi$ standard-deviation results seemed to indicate a second source of $\phi$ fluctuations being caused by strong nonlinearities at the level of the component rhythmic units. Importantly, the coordination was also affected by the social competence manipulations: HH and LL pairs demonstrated more breakdowns in phase locking than did the HL pair. Moreover, the HH pairs, in producing greater fluctuations in $\phi$ for

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pendulum combinations of equal length, did not seem to use the dynamical strategy for producing stable phase locking that has been widely observed and produced. An interpretation of the results is sought in the social control aspect of social competence.

A profound but not much studied aspect of human social behavior is our ability to coordinate our movements with another person. A striking property of natural between-person interactions is the degree of between-person coordination or what has been called *interactional synchrony*: The spatial and temporal aspects of two individuals’ movements are related congruently. For example, videotape analysis has revealed synchronization of the listener's body with the speech of the speaker (Condon, 1974). In particular, a listener's body movements parallel the emerging units of the speaker's speech. It has been noted that the observed movements are not just one person's reacting to another in a stimulus-response fashion but a mutual interaction, a cooperation, a harmonizing of the two behaviors (Bernieri & Rosenthal, 1991). It seems that the existence of a *mutual goal* has organized the two individuals into a single "organism" (Asch, 1952; Newton, Hairfield, Bloomingdale, & Cutino, 1987) or a dyadic synergy (Schmidt, Carello, & Turvey, 1990).

Such mutual goals underlying between-person coordination can vary in their obviousness. For example, in formal coordination settings such as manual work tasks, sports, or dance, the between-person coordinative goals are obvious or explicit. In everyday interactions, however, less obvious or implicit between-person coordinative goals are found. Implicit mutual goals characterize a conversation between two individuals or the mutual avoidance of individuals in walking down the hall. The degree of explicitness of a mutual task can be used to differentiate two lines of research that have been established for investigating between-person coordination. One line investigates the effects of social variables on the degree of between-person coordination in settings where the interactions are natural and the goals are implicit. The other investigates the effects of physical variables on interactional synchrony using interactions that are quite stereotyped and goals that are very explicit, with the hope of modeling the coordinative processes involved in interpersonal coordination.

**EFFECTS OF SOCIAL VARIABLES ON BETWEEN-PERSON COORDINATION**

One goal of the first line of research has been to determine how the degree of between-person coordination or interactional synchrony changes with social or personality variables. For example, a teacher and student pair that report having
better rapport with one another are found to have a higher degree of interactional synchrony (Bernieri, 1988). Women interacting with their own children are perceived to demonstrate a greater degree of interactional synchrony than those women interacting with other children (Bernieri, Reznick, & Rosenthal, 1988). A link has also been found between interactional synchrony and pathology. People who have serious communication disorders and those with severe psychological pathologies, such as schizophrenia, appear to be less interactionally synchronous than normals (Condon, 1982). It seems that their disability does not allow a dyadic synergy to emerge in their interactions with others. Why this is and what coordination processes are not able to function are not known.

Along these lines an obvious question to investigate is whether interactional synchrony differs for people who differ in their social skills or social competence (SC). Socially competent people possess greater skill in social interactions and should accordingly be more adept at both verbal and nonverbal communication. Conversely, socially incompetent people should be relatively unskilled in verbal and nonverbal interaction. A socially competent person is presumably more adept at perceiving various possibilities for social action, perhaps by being attuned to the facts of a situation and what type of action it requires. Hence, SC might be defined as the ability of the organism to perceive the affordances of the social environment (Boudreau, 1991/1992; Gibson, 1979/1986). The question is whether or not an individual’s potential to be social as defined by SC will affect the degree of between-person synchrony observed in his or her interactions and in what way. An intuitive hypothesis is that higher SC individuals will have more coordinated interactions: They in general will be able to perceive the social properties needed to achieve the mutual goals of the interactions in which they participate. The physical properties of interpersonal coordination reveal a method that can be used to investigate this hypothesis.

EFFECTS OF PHYSICAL VARIABLES ON BETWEEN-PERSON COORDINATION

A second line of research has investigated the coordinative processes involved in interactional synchrony. The general question is how between-person coordination and its dyadic synergies can be modeled. This question has been addressed by employing methodologies that have been used in investigations of within-person coordination, adapting them to a between-person setting. Usually this has involved the visual coordination of rhythmically moving limbs such that they are oscillating at a common tempo in a specific relative phase pattern—the symmetric relative phase mode, where two limbs are in the same part of a cycle at the same time, or alternate relative phase mode, where two limbs are in opposite parts of a cycle at the same time. This methodology manipulates physical
variables that affect the oscillatory state of the system to evaluate the underlying coordinative processes. Compared to the sorts of natural interactions that provide the focus of investigations of social variables on between-person coordination, however, the interactions required to investigate the underlying processes are relatively stereotyped and the mutual goal that the dyad is trying to achieve is explicit. Two physical variables that have been used to manipulate the coordinative state in these between-person coordination experiments are the coupled frequency of oscillation \( \omega_c \) and the difference in the limbs' preferred frequency \( \Delta \omega \). Because these manipulations are central to the present study, the results of these studies are now reviewed briefly.

When two individuals sitting side by side are asked to visually coordinate the oscillation of their lower legs in the sagittal plane in either the symmetric or alternate relative phase mode at a frequency specified by a metronome pulse, manipulations of \( \omega_c \) have shown that a breakdown of the alternate phase mode (with a transition to the symmetric mode) occurs at high frequencies of oscillation (Schmidt et al., 1990). These results replicate results from within-person bimanual coordination of rhythmically moving index fingers and wrists (e.g., Kelso, 1984; Kelso, Scholz, & Schöner, 1986; Scholz, Kelso, & Schöner, 1987). The research on the within-person "phase transition" has demonstrated that the states and the changes in state of the rhythmically coordinated units can be modeled as a dynamical system, namely, as the states of a coupled-oscillator dynamical system that has two stable attractor states which define the symmetric mode at 0° relative phase and the alternate mode at 180° relative phase (Haken, Kelso, & Bunz, 1985). The evidence for such a dynamical characterization leads from the fact that the phase transition satisfies all the hallmark criteria (Gilmore, 1979; Turvey, 1990) of a very general kind of nonlinear change of state found in a great variety of physical systems including coupled oscillators.

Interestingly, Schmidt et al. (1990) observed some of the same critical properties in the visual, between-person breakdown of the alternate relative phase mode. The presence of these properties verifies that the switching of coordination modes in between-person, visual coupling has a dynamical basis as well. In the between-person case, however, there is no neural linkage of the two limbs; the only linkage that exists is in the optic array. The similar breakdown in coordination mode for two very different kinds of couplings (neural and optical) implies that the principles governing the oscillatory control structures are dynamical and can operate over either linking medium. The power of dynamical models is exposed in this context because the principles involved are abstract enough to operate in varied circumstances. Further, the between-person phase transition results suggest that linkages through perception are a robust enough basis for the dynamical interaction and, hence, dynamical coordination of effector systems.

The investigation of a second physical variable and its effect on between-
person coordination also supports the dynamical characterization of the
between-person rhythmic "coordinative structure" as a coupled-oscillator re-
gime. As conceived by von Holst (1939/1973), the coordination of biological
rhythmic movements is characterized by two competing dispositions: a main-
tenance tendency and a magnet effect. The maintenance tendency is the disposition
of the rhythmic unit (Central Pattern Generator, rhythmically moving append-
age, etc.) to maintain its own preferred oscillation frequency—in short, to resist
entrainment on the basis of its own internal dynamic. The magnet effect is the
tendency for the units to draw each other to their respective oscillation
frequencies and is founded on processes that bring the rhythmic units into an
entrained state. To anticipate, the maintenance tendency and magnet effect
may provide a basis for understanding the effect of social competence on
interactional coordination.

Experimentally one can investigate the relation between these reciprocal
processes of rhythmic coordination by manipulating the dynamical similarity of
the rhythmic units, in particular, the preferred frequency of the individual
limbs. Manipulating the difference between the preferred frequencies of the
individual limbs, denoted by the variable $\Delta \omega$, is tantamount to manipulating
the magnitude of the maintenance tendency. Such a methodology was em-
ployed by von Holst (1939/1973) in his study of the coordination of fins in the
fish Labrus by investigating the coordinated behavior of fins of different sizes
and, consequently, of different uncoupled preferred frequencies. This kind of
methodology also forms the basis of a human within-person bimanual rhythmic
coordination paradigm (Kugler & Turvey, 1987) in which an individual oscill-
ates hand-held pendulums from the wrist joint in the sagittal plane. In this
wrist-pendulum methodology, the preferred frequency of a rhythmic unit can be
manipulated by changing the inertial properties of the hand-held pendulum
(i.e., the length of the rod and the mass of an attached bob). Accordingly, the
maintenance tendencies of the individual rhythmic units that must be overcome
by magnet effect processes can be manipulated by altering the difference
between the two wrist-pendulums' inertial loadings. By performing such manip-
ulations, the experimenter sets up the initial conditions for the interplay of
maintenance and magnet effect processes. One may think of the manipulation
of $\Delta \omega$ as indexing the magnitude of the competition or cost that the coordinative
processes must overcome.

Two coordination phenomena are observed in the within-person coordina-
tion of rhythmically moving limbs under manipulation of $\Delta \omega$. As $\Delta \omega$
deviates from 0 (i.e., as the inertial loadings of the two limbs differ more and more),
the mean relative phase $\phi$ deviates proportionally from intended phase angle (0° or
180° depending on the phase mode) such that the intrinsically faster rhythmic
unit leads in the cycle (Rosenblum & Turvey, 1988; Schmidt, Beek, Treffner, &
Turvey, 1991; Schmidt, Shaw, & Turvey, 1993; Sternad, Turvey, & Schmidt,
1992; Turvey, Rosenblum, Schmidt, & Kugler, 1986) and the fluctuations in $\phi$
increase (Schmidt et al., 1991; Schmidt et al., 1993). Hence, with increasing the magnitude of the maintenance tendency (i.e., $|\Delta \omega|$), consequences or “corrections” are seen in the coordination as indexed by the coordination variable $\phi$, namely, a relative phase “lag” and relative phase fluctuations.

Importantly, if the wrist-pendulum paradigm is adapted to a between-person situation such that two people sitting side by side visually coordinate the pendulums swung in their outer hands, one also observes an increase in relative phase lag and an increase in relative phase fluctuations with $|\Delta \omega|$ (Schmidt & Turvey, 1994). In brief, the effects of scaling $\Delta \omega$ are the same regardless of whether the coupling of the rhythmic units is within or between persons. The same coordination (i.e., magnet effect) processes seem to be at work whether the coordination involves one nervous system or two, or whether the coupling medium is the optic array or neural tissue.

The scale independence of the phenomena is indicative of very general organizing principles. As a matter of fact, these phenomena are just those one would expect if a coupled-oscillator dynamic was involved in the coordination of rhythmically moving limbs. Assuming that rhythmically moving limbs can be modeled as limit cycle oscillators interacting according to some weak coupling that is a function of the oscillator’s relative phase, the behavior of the relative phase under manipulations of $\Delta \omega$ can be modeled by the following equation:

$$\dot{\phi} = \Delta \omega + k \sin(\phi)$$

(1)

where $\phi$ is the relative phase angle, $\dot{\phi}$ is its rate of change, $\Delta \omega$ is the difference in the preferred frequencies of the component oscillators, and $k$ indexes the coupling strength. This model of rhythmic coordination, first introduced to understand the coordination of neural oscillators (Cohen, Holmes, & Rand, 1982; Rand, Cohen, & Holmes, 1988), has been used to evaluate the local behavior of interlimb relative phasing near the attractor points of $0^\circ$ and $180^\circ$ (Schmidt et al., 1993; Sernad et al., 1992). Equation 1 can be understood as a special case of the Haken et al. (1985) model of the global behavior of relative phase (Fuchs & Kelso, in press; Schmidt & Turvey, in press). Although this simpler model cannot be used to model the global behavior of relative phase (e.g., multistability, transitions between coordinative patterns, hysteresis), it provides a relatively direct and simple means of understanding steady-state relative phase behavior near the attractor points, in general, and the relative phase “lag” and fluctuations produced by scaling $\Delta \omega$, in particular.

Equation 1 will produce coordinated (i.e., phase-locked) rhythmic behavior when $\dot{\phi} = 0$. This state can be understood as a balancing of the equation’s “maintenance tendency term” $\Delta \omega$ with its “magnet effect term” $k \sin(\phi)$. Under such a condition, the scaling of $\Delta \omega$ away from 0 under a constant coupling strength $k$ produces (a) a change in the attractor location of the regime and (b) a deformation of the potential well such that its concavity decreases (Figure 1).
The change in attractor location explains the linear change in phase lag with deviation of $\Delta \omega$ from 0. The phase lag is a consequence of the coupled-oscillator regime’s equilibrium state changing location in its state space. Further, the increase in the deformation of the potential well indicates a decrease in the strength of the attractor: Any perturbation of a given force will cause a greater temporary change in the system’s state (i.e., the state will travel farther along the $x$-axis of the potential well) if the potential well is less concave. Such a state of affairs produces an increase in relaxation time (i.e., time to return from a perturbation) and an increase in fluctuations given a constant source of noise (Schöner, 1989). Given this weakening of the attractor with the scaling of $\Delta \omega$ away from 0 and assuming a constant source of noise, the model predicts that fluctuations should increase with $|\Delta \omega|$.

Recent studies have also investigated the effect of the simultaneous manipulation of the two variables $\omega_c$ and $\Delta \omega$ on rhythmic coordination. In the within-person coordination of wrist pendulums, as the frequency of oscillation $\omega_c$ was increased, greater phase lags were observed with changes in $\Delta \omega$ (Schmidt et al., 1993; Sternad et al., 1992). This $\omega_c$ exaggeration of the $\Delta \omega$–mean $\phi$ effect has also been observed in the between-person coordination of hand-held pendulums (Schmidt, Bienvenu, O’Brien, Fitzpatrick, & Carello, 1992). How are these results to be explained in view of the local dynamical model (Equation 1)? Assuming that the system is phase locked (i.e., $\phi = 0$), the coupling strength $k$ of the model can be estimated using a regression analysis in which $\sin(\phi)$ (sine of the observed mean phase) is regressed on $\Delta \omega$. The significance of the regression is an estimate of the fit of the model in Equation 1 to the data; the resulting slope is an estimate of the dynamic’s coupling strength $k$. Using this regression technique, coupling strength $k$ has been shown to be inversely related to $\omega_c$: The strength of the coupling becomes weaker with increasing frequency and the weakening of the coupling causes the exaggeration of the $\Delta \omega$-scaled phase lag.
In summary, the effect of two physical variables, $\omega_c$ and $\Delta \omega$, on between-person rhythmic coordination indicates that (a) a regime composed of a coupled-oscillator dynamic is assembled and is the basis for the emergent dyadic synergy or between-person coordinative structure, (b) the same dynamic seems to be assembled in within- and between-person coordination, and (c) the between-person dyadic synergy is formed on the basis of the optical information available about the component limbs' dynamical state.

**EXPERIMENTAL OVERVIEW**

The purpose of this study is to combine the two previously disparate lines of research on between-person coordination by simultaneously manipulating both social and physical variables. Previous investigations of the social variables have involved naturalistic coordinations with implicit goals. The problem associated with such a methodology is the difficulty in measuring the individual persons' movements and their coordination. Questions arise to what effector trajectories should be measured and how to evaluate the degree of interpersonal coordination. By using the more stereotypic coordination tasks that have been used in studies of the effects of physical variables, these problems can be circumvented. In addition, how the social variables interact with the dynamical nature of the between-person coordinative structures can be evaluated, possibly leading to a new understanding of the social variables involved.

The method used here involves having dyads that differ in SC perform a task that consists of the visual coordination of hand-held pendulums in the alternate phase mode. Three SC conditions were used: dyads in which both participants had high SC (HH pairs), dyads in which both participants had low SC (LL pairs), and dyads in which one participant had high and the other had low SC (HL pairs). The two physical variables previously studied, $\omega_c$ and $\Delta \omega$, are manipulated to provide an index of the dynamical properties of the coordination. The degree of coordination can be measured by the mean relative phase angle $\phi$ formed between the two pendulums as well as by $\phi$'s variability.

Several questions can be addressed using this methodology. Coordination, as indexed by mean $\phi$, may break down when the frequency of oscillation is high (Schmidt et al., 1990) but will the breakdown differ for SC group? Will the strength of the relative phase attractor (as indexed by the phase fluctuations) and the strength of the coupling (as indexed by the parameter $k$ in Equation 1) differ for SC groups? Answering these questions will allow an appreciation of whether and how variables at the social scale affect the dynamical variables of coordination. Given the intuitive hypothesis, stated earlier, that socially competent individuals should be “good at coordinating with another,” we may expect the HH pairs to exhibit the most stable coordination, the LL pairs to demonstrate the least stable coordination, and the HL pairs to be somewhere in
the middle. By investigating the number of coordination breakdowns, the fluctuations of relative phase, and the coupling strength associated with the coupled-oscillator dynamic, this hypothesis can be evaluated.

METHOD

Participants

Participants were chosen from a pool of 271 University of Connecticut students who, in partial fulfillment of a course requirement, completed a shortened version of the Riggio Social Skills Inventory that assessed SC (Boudreau, 1991/1992; Riggio, 1986). The test has a possible score range of 60 to 540, where higher scores reflect greater SC. The present sample had a score range of 197 to 425 with a mean of 352. Students scoring in the upper and lower quartiles of the original sample were contacted by telephone to arrange for participation in the coordination experiment. Nine upper quartile and 9 lower quartile individuals were designated high and low social competents, respectively. To insure the validity of the SC estimates, one of the experimenters, naive to the actual competence score, rated the individual participants on SC using the behavior categories of amount of eye contact, body posture, conversational skills, and degree of perceived comfort. Her ratings correlated significantly with the Social Skills Inventory ($r = .70, p < .002$) indicating satisfactory validity for the scale.

These 18 participants were between 18 and 22 years of age, were right-handed, and had no motor disabilities. They were assigned to form nine pairs such that three pairs consisted of two high-competent individuals (HH), three pairs consisted of two low-competent individuals (LL), and three pairs consisted of one high-competent and one low-competent individual (HL). Each participant served in only one pair.

Materials

Participants sat in student desks approximately 1 m from each other facing the same direction (Figure 2). A 1-m² plywood board with movement acquisition microphones in each corner was on the floor between the participants. Arm rests attached to the desk surfaces supported the arms so that hand-held pendulums would oscillate parallel to the sagittal plane about an axis in the wrist. Because the movement acquisition apparatus was sonic, the microphone surface was shielded from auditory reflections from hard surfaces in the room by enclosing it within 0.7-m-high foam padded walls. These created a kind of pen in which the pendulums were swung.

Pendulums were constructed using the specifications described in Kugler and Turvey (1987). They consisted of an ash dowel with a bicycle hand grip at the
Additional masses were attached to a 10-cm-long bolt that was drilled through the dowel at right angles 2 cm from the bottom so as to bring the total mass of the pendulum to 0.2 kg. Pendulums were either 0.31 m or 0.75 m long and were paired as long-short, short-short, or short-long. Previous studies (e.g., Turvey, Schmidt, Rosenblum, & Kugler, 1988) have found that the preferred frequencies of oscillation are near the gravitational frequency of the wrist-pendulum system. The preferred frequencies of our physical pendulums considered as gravitational pendulums ($\omega_g$) are displayed in Table 1, along with the difference in the preferred frequencies $\Delta \omega$ (= left $\omega_g$ − right $\omega_g$). Note that negative $\Delta \omega$ values indicate pendulum pairs in which the left system is larger and has a lower frequency of oscillation than the right; positive $\Delta \omega$ values indicate pendulum pairs in which the right system is larger and has a smaller frequency of oscillation than the left. Each participant dyad was asked to coordinate the oscillation of all three pendulum combinations.

Wrist-pendulum movement trajectories were collected using a 3-Space Sonic Digitizer (Science Accessories Corporation, Stratford, CT). A sonic emitter was affixed to the end of each pendulum. A sonic “spark” issued from each emitter 90 times per second. The digitizer operates by registering each emission using three microphones arranged to form a square grid. The digitizer calculates the distance of each emitter from each microphone, thereby pinpointing the position of the emitters in three dimensions at the time of the emission. This

<table>
<thead>
<tr>
<th>System</th>
<th>Left $\omega_g$</th>
<th>Right $\omega_g$</th>
<th>$\Delta \omega$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-long</td>
<td>0.893</td>
<td>0.575</td>
<td>0.32</td>
</tr>
<tr>
<td>Short-short</td>
<td>0.893</td>
<td>0.893</td>
<td>0.00</td>
</tr>
<tr>
<td>Long-short</td>
<td>0.575</td>
<td>0.893</td>
<td>-0.32</td>
</tr>
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slant-range information was stored for later use on a 80286-based microcomputer using MASS digitizer software (Engineering Solutions, Columbus, OH). This software and analogous routines written on a Macintosh II use the slant-range time series to calculate the primary angle of excursion of the pendulums and their relative phase angle $\phi$. An electronic metronome with an auditory pulse was used to help the participants determine the oscillation tempo required for the different conditions.

Procedure and Design

Participant pairs were asked to coordinate one of the three possible combinations of pendulums in Table 1 isochronously (at the same tempo) and in the alternate phase mode. The frequency of oscillation ($\omega$) at which the individuals were to coordinate the pendulums was one of two preset frequencies, 0.65 Hz or 1.5 Hz. These frequencies were chosen because low frequency was in the stable frequency range for the alternate-mode relative phasing whereas the high frequency was near the limit of this range (i.e., breakdowns in coordination have been observed at this frequency in previous between-person coordination studies; Schmidt et al., 1990). The metronome was turned on at the preset frequency before data recording began.

Each participant pair was given instructions and allowed to practice before the beginning of a session. Participants were told to place the appropriate forearm squarely on the arm rests and to hold the pendulums firmly so that as much of the rotation of the pendulum as possible was created about the wrist joint rather than about the finger joints. Further, each participant was instructed to look at his or her partner's pendulum and to oscillate in coordination with the other person at the frequency dictated by the metronome pulse and in the alternate relative phase mode. Participants were told that the coordination might be difficult to maintain in some conditions; in such cases, they were instructed to try to maintain the specified frequency of oscillation and to stay in the alternate phase pattern. Participants were repeatedly reminded to watch the other person's pendulum at all times. At the beginning of each trial, the pairs were allowed as much time as needed to achieve the goal of the condition. Data recording began after both participants indicated that they were ready. They were allowed to rest between the trials of a session as needed.

The design of the experiment was a $3 \times 2 \times 3$ factorial with a between-subjects (in this case, dyads) variable of SC group (HH, LL, or HL) and within-subject (again, for dyads) variables of frequency condition ($\omega_c = 0.65$ and 1.5 Hz) and pendulum combination ($\Delta \omega = -0.32$, 0, and .32). Each participant pair performed twenty 40-s trials. The trials were randomly distributed among the conditions. Due to experimenter error, not all within-subject conditions contained the same number of observations; however, because means are entered into the analyses of variance (ANOVAs), this does not pose a problem for the statistical analyses.
Data Reduction

The digitized position time series of the wrist-pendulum systems on each trial were subjected to software analyses to determine the frequency and angular excursion of each wrist-pendulum system and the time series of the relative phase angle $\phi$ between the two wrist-pendulum systems.

A peak-picking algorithm was employed to determine the time of maximum forward extension of the wrist-pendulum trajectories. From the peak extension times, the frequency of oscillation for the $n$th cycle was calculated as:

$$f_n = 1/(\text{time of peak extension}_{n+1} - \text{time of peak extension}_n).$$  \hspace{1cm} (2)

From the peak extension and flexion positions, the angular excursion for the $n$th cycle was calculated as

$$\theta_n = (\text{position of peak extension}_n - \text{position of peak flexion}_n).$$ \hspace{1cm} (3)

The mean frequency of oscillation and angular excursion for a trial were calculated from these cycle estimates, $f_n$ and $\theta_n$ and the mean frequency of oscillation and angular excursion for a particular pair was calculated from these values.

The phase angle of each wrist-pendulum system ($\theta_i$) was calculated for each sample (90/s) of the position time series to produce a time series of $\theta_i$. The phase angles of wrist pendulum $i$ at sample $j$ ($\theta_{ij}$) was calculated as

$$\theta_{ij} = \arctan \left( \frac{x_{ij}^*}{\Delta x_{ij}} \right)$$ \hspace{1cm} (4)

where $x_{ij}^*$ is the velocity of the time series of wrist pendulum $i$ at sample $j$ divided by the mean frequency for the trial, and $\Delta x_{ij}$ is the position of the time series at sample $j$ minus the average position for the trial. The relative phase angle ($\phi$) between the two coupled wrist-pendulum systems was calculated for each sample as the $\theta_{left \ j} - \theta_{right \ j}$. Each $\phi_i$ should equal 180° in perfect alternate relative phase coordination. The $\phi$ time series allows an evaluation of how the participants satisfied this task demand. The evaluation was accomplished in several ways. First, the mean $\phi$ for a given pair was calculated for each trial and condition. Second, to determine the variability of this time series, the standard deviation of $\phi$ was calculated for each trial and then averaged across all trials of a condition.

RESULTS AND DISCUSSION

Frequency of Oscillation

The mean frequency of oscillation was submitted to a $3 \times 2 \times 3$ ANOVA, with a between-dyads variable of SC group and within-dyad variable of frequency
condition and pendulum combination, to verify that the condition's prescribed frequency of oscillation was actually performed. A main effect for frequency condition, \( F(1, 6) = 2003.60, MS_e = 0.005, p < .001 \), indicates that the observed frequencies were near the metronome-specified values (0.71 and 1.55 for the 0.65-Hz and 1.50-Hz conditions, respectively). The deviations from intended frequencies may be due to frequency transients caused by coordination breakdowns (described later). A significant three-way interaction was also found, \( F(4, 12) = 3.34, MS_e = 0.001, p < .05 \). Simple-effects analyses at each SC group revealed a marginal trend \( (p = .09) \) for the LL pairs who tended to increase their tempo when oscillating the \( \Delta \omega = -.32 \) pendulum combination in the slower frequency condition. Apart from this, all participant groups were establishing the tempo of their rhythmic movements equally.

Angular Excursion

Whereas the frequency of oscillation was specified by a metronome, the angular excursion or spacing of the oscillation was chosen by the individuals. A three-way ANOVA of the same design was performed on the mean angular excursion of the pairs and revealed a main effect of frequency, \( F(1, 6) = 83.86, MS_e = 15.72, p < .001 \), in which the oscillation excursion was smaller for the faster frequency condition \((M = 24.64^\circ)\) than for the slower one \((M = 34.52^\circ)\). This result corroborates previous findings in which the oscillation spacing related inversely to the frequency of oscillation (Feldman, 1980; Kay, Kelso, Saltzman, & Schöner, 1987). The analysis also revealed a significant interaction between frequency condition and pendulum combination, \( F(2, 12) = 11.77, MS_e = 13.67, p < .01 \). As shown in Figure 3 and verified by simple-effects analyses, oscillation spacing was affected by pendulum combination (i.e., \( \Delta \omega \)) for the faster frequency condition \((p < .001)\) but not for the slower frequency.

![Figure 3](image_url)

**Figure 3** Half-cycle angular excursion as a function of \( \Delta \omega \) for each frequency condition.
condition \((p > .05)\). The excursions were the largest in the symmetrical pendulum combination, where \(\Delta\omega = 0\). This may be explained by the fact that the pendulums being coordinated are the short ones (0.31 m) and, hence, may be harder to track visually especially at the higher frequency of oscillation. An alternative explanation is provided in the General Discussion. No significant effects of SC group were found.

**Mean Relative Phase \(\phi\)**

A three-way ANOVA on mean relative phase angle \(\phi\) yielded a significant main effect for frequency, \(F(1, 6) = 100.01, MS_e = 258.8, p < .001\), indicating that the relative phase values were nearer the criterial 180° alternate mode for the slower frequency (\(M = 171.0°\)) than for the faster frequency (\(M = 127.2°\)). The analysis also revealed an SC Group \(\times\) Frequency interaction, \(F(2, 6) = 5.80, MS_e = 241.71, p < .03\). As shown in Figure 4 (top) and verified in simple-effects tests, SC groups did not differ at the slower frequency \((p > .05)\). At the faster frequency, however, SC mattered \((p < .05)\): The HH \((M = 113.45°)\) and LL \((M = 118.2°)\) groups did not differ from each other but both deviated farther from 180° \((p < .05)\) than did the HL group \((M = 150.1°)\).

The magnitudes of mean \(\phi\) for the faster frequency suggest that a stable coordination or phase locking was not attained in a large proportion of the trials. Taking our lead from Schmidt et al. (1990), who based their criterion on previous within-person rhythmic coordination studies, alternate mode coordination is said to be phased locked for mean \(\phi\) in a range of 180° \(\pm 50°\). Using this criterion, the mean \(\phi\) magnitudes for the HH and LL groups at the faster frequency are not in the phase-locked range. To evaluate the degree to which phase locking was established in the various conditions, the percentage of phase-locked trials was calculated for each condition and these values were submitted to a three-way ANOVA. The analysis yielded a significant main effect for frequency, \(F(1, 6) = 38.44, MS_e = 816.3, p < .001\), indicating that, as expected, a majority of trials (87%) were phase locked at the slower frequency whereas fewer than half the trials (39%) were phase locked at the faster frequency. Further, the main effect of SC group, \(F(1, 6) = 7.83, MS_e = 929.06, p < .05\), indicates that the HH and LL pairs were less phase locked (51% and 52%, respectively) than the LH pairs (86%). Finally, a marginal interaction (Figure 4, bottom) between SC group and frequency condition, \(F(2, 6) = 4.58, MS_e = 816.3, p = .06\), and its simple effects indicate that the SC group differences occurred at the faster frequency \((p < .05)\) but not at the slower frequency \((p > .05)\). No significant effects of \(\Delta\omega\) were observed.

To evaluate if the coupled oscillator dynamic of Equation 1 was assembled when the coordination was phase locked, a regression analysis was performed to determine the coupling strength \(k\) (see explanation of Equation 1). SC group was included as a factor in the regression model to ascertain whether the intercepts
or slopes of the regressions of $\sin(\phi)$ on $\Delta \omega$ differed for the social variable. Because the regression technique assumes stable phase-locking behavior, and the stable trials at the higher frequency were too few, the regression was performed on the stable trials of the 0.65-Hz frequency condition only. Although the SC-group main effect was not significant, $F(2, 79) = 0.93$, $M_{S_e} =$
0.10, \( p > .05 \), the analysis revealed a significant effect of \( \Delta \omega \), \( F(1, 79) = 8.66, MS_e = 0.10, p < .01 \), and a marginal interaction of SC group and \( \Delta \omega \), \( F(2, 79) = 2.88, MS_e = 0.10, p = 0.06 \). This interaction became significant (\( p < .05 \)) when three HH data points were eliminated on the basis of their having extremely high standard deviations of \( \phi \) (see next section).

The \( \Delta \omega \) main effect reveals a general fit of Equation 1 to the data: Changes in \( \Delta \omega \) result in linear changes in relative phase lag (Figure 5). The interaction suggests that the slopes of these linear changes differ for the SC groups. Simple regressions demonstrate that there is a significant change of \( \phi \) with \( \Delta \omega \) for the LL and HL groups yielding slopes of 0.119 (\( p < .001 \)) and 0.072 (\( p < .05 \)), respectively, but no significant change of \( \phi \) with \( \Delta \omega \) for the HH group (\( p > .05 \)). A post hoc slope comparison indicates that the slopes of HL and LL groups did not differ significantly from each other (\( p > .05 \)), HH and LL differed marginally (\( p = .06 \)), and HH and LL differed significantly (\( p < .01 \)). These results suggest that, in producing interpersonal coordination, the coupled-oscillator dynamic was used by the low- and mixed-competence pairs but was not used by the high-competence pairs. This dissociation among SC groups for the stable coordination trials may explain why HH pairs demonstrated more breakdowns in coordination at the high frequency—they never assembled a coupled-oscillator regime.

Fluctuations in Relative Phase

A three-way ANOVA performed on the standard deviations of \( \phi \) yielded a significant three-way interaction, \( F(4, 12) = 4.99, MS_e = 21.22, p < .05 \) (Figure 6). Mean \( \phi \) standard-deviation magnitudes greater than 40° have been associated with non-phase-locked coordination (Schmidt et al., 1992). Using this criterion, as has been demonstrated in the mean \( \phi \) results, phase locking did not occur on average at the faster frequency (Figure 6, left). A simple-effects analysis at this frequency revealed no effect of SC group or \( \Delta \omega \). At the slower frequency (Figure 6, right), the analysis yielded a significant SC Group \( \times \) \( \Delta \omega \) interaction, \( F(4, 12) = 4.46, MS_e = 29.59, p < .05 \), which was rooted in an SC-group significant difference at \( \Delta \omega = 0 \) (\( p < .001 \)). With equal length, short pendulums, achieving stable phase locking remained difficult for the HH group.

One may well ask whether the same patterning of results would occur if the slower frequency \( \phi \) standard-deviation data were restricted to just the phase-locked trials (i.e., to trials where the mean \( \phi \) was between 130° and 230°). Further, inspection of the stable trial means for this slower-frequency condition revealed three aberrantly high values (< 45°) in the HH group, indicating that phase locking was very unstable for these trials. Eliminating these trials and performing an ANOVA on only the phase-locked slower-frequency data still yielded a marginal interaction of SC group and \( \Delta \omega \), \( F(4, 12) = 2.89, MS_e = \)
FIGURE 5 Mean relative phase $\phi$ as a function of $\Delta \omega$ plotted separately for each SC group. Because relations between these variables are taken as a test of the dynamical model expressed in Equation 1, just the stable phase-locked trials of the slow frequency condition were used. Regressions were significant for the LL and HL pairs but not the HH pair (see text).
19.49, $p = .06$. This supports the same conclusion as the previous analysis: The SC group's $\phi$ standard deviations differed only when $\Delta \omega = 0$.

Given the marginal nature of this interaction, it ought to be understood in the context of the $\Delta \omega$ main effects that were found in both analyses. These main effects—all data: $F(2, 12) = 6.47$, $MS_e = 29.59$, $p < .05$; just phase-locked: $F(2, 12) = 5.39$, $MS_e = 19.49$, $p < .05$—indicate that in general there is the tendency for $\Delta \omega = 0$ to have relatively high fluctuations (Figure 6, right). This result contrasts with a typical finding from both between- and within-person investigations, that as $\Delta \omega$ deviates from 0 (i.e., the pendulums to be coordinated begin to differ in size), phase fluctuations are typically found to increase (Schmidt et al., 1993; Schmidt & Turvey, 1994). However, further analysis of the data of Sternad et al. (1992) suggests that the length of the pendulums to be coordinated is a significant factor in the production of relative phase fluctuations. In particular, pendulum combinations of smaller average magnitudes tend to produce more fluctuations (the $\beta$s on the pendulum lengths are negative, $p = .01$). Tellingly, one difference between this study and the previous investigation of between-person pendulum coordination is in the composition of $\Delta \omega = 0$ pendulum combinations. In the present work, $\Delta \omega = 0$ consists exclusively of two short pendulums (0.31 m), whereas, in the previous study (Schmidt & Turvey, 1994), $\Delta \omega = 0$ was also achieved using some long–long (both 0.60 m) and some short–short (both 0.31 m) combinations. Our understanding of these results is in terms of the composition of the oscillatory units that are being coordinated. Rosenblum and Turvey (1988) found that fluctuations in periodic timing become greater as the pendulum to be oscillated decreases in size. They suggested that wrist-pendulum coordination consists of two cooperating dynamics: (a) a harmonic dynamic, related to the physical pendulum's motion, and (b) a relaxation dynamic, related to the neuromuscular forces that maintain the pendulum's motion. They concluded that the smaller wrist-pendulum trajec-
eries are less stable because the relaxation dynamic component of the oscillation is more prominent. Recent work (Beek, Schmidt, Morris, Sim, & Turvey, in press), using a dynamical decomposition of wrist-pendulum accelerations in which the relative contribution of the relaxation and harmonic terms can be estimated, verified Rosenblum and Turvey's conjecture: The relative magnitudes of nonconservative (i.e., relaxation) coefficients increased as the pendulums decreased in length.

Hence, the present results along with our analysis of the Sternad et al. (1992) fluctuation data suggest that the \( \phi \) fluctuations can come from two sources. The first source is the state of the coupling dynamic whose attractor is represented in Figure 1. This dynamic exists on a relatively macroscopic level of the coupled system. It predicts that as \( \Delta \omega \) deviates from 0, fluctuations in \( \phi \) will increase. The second source of \( \phi \) fluctuations is the relaxation dynamic that is assembled to oscillate a single pendulum about the wrist joint. This dynamic exists on the local or microscopic level of the coupled system. It predicts, alternatively, that as the pendulum length decreases, the timing fluctuations increase and, hence, \( \phi \) fluctuations will increase. The present fluctuation data can be understood as resulting from a competition of these two sources because \( \Delta \omega \) and pendulum length are correlated. These results have not been previously observed because the competition (and the correlation) did not exist in previous studies.

This argument can be evaluated by a multiple-regression analysis on the stable phase-locking data that uses indices of the coupled and local oscillator sources of \( \phi \) fluctuations as independent variables and \( \phi \) fluctuations as a dependent variable. For the coupled-oscillator index, the absolute deviation from intended phase is used (i.e., \(|\phi - 180^\circ|\)). Because it indicates the distance the coupled-oscillator point attractor is from the intended phase (Figure 1) and, hence, how deformed the potential well or how weak the attractor is, a significant positive relation with the \( \phi \) fluctuations would reflect the coupled-oscillator dynamic of Equation 1 as a fluctuation source. For the local oscillator index of the relaxation dynamic, the length of the individual pendulums is used. By the foregoing arguments, the smaller pendulum's movement should be composed of a relatively stronger relaxation dynamic (compared to the harmonic dynamic assembled) and, hence, should cause more fluctuations. Therefore, a significant inverse relation of these variables with \( \phi \) fluctuations would indicate a contribution of the local relaxation dynamic. The overall model for the analysis was significant, \( R^2 = .24, F(3, 81) = 8.5, p < .001 \). The analysis revealed a significant positive coefficient for the absolute deviation from intended phase (\( \beta = 0.21, p < .01 \)) and negative coefficients for the individual pendulum lengths (\( L_{\text{left}}: \beta = -19.87, p < .001; L_{\text{right}}: \beta = -8.32, p = .13 \)). These results support the argument that two sources (one on the coupled-oscillator level and one on the local-oscillator level) are contributing to the fluctuations in \( \phi \). Further, the marginal interaction of pendulum combination with the SC group from the previous \( \phi \) standard-deviation ANOVA, if reliable,
indicates that the effect of the local-level relaxation dynamic on the $\phi$ fluctuations is particularly evident in the HH pairs.

GENERAL DISCUSSION

Interpersonal coordination, under manipulation of both social (competence) and physical ($\omega_c$ and $\Delta\omega$) variables, was examined using a relatively stereotyped task of wrist-pendulum coordination in the antiphase mode. This task permits the measurement of the degree of interpersonal coordination in terms of both the mean value of the relative phase angle $\phi$ formed between the rhythmic units and the variability of $\phi$. Effects of $\omega_c$ concurred, for the most part, with previous within-person (Kelso, 1984; Kelso et al., 1986; Scholz et al., 1987) and between-person (Schmidt et al., 1990) coordination studies. More breakdowns in relative phasing were observed at the faster frequency (61% of the trials) than at the slower frequency (13% of the trials), which the lack of phase locking reflected in enhanced $\phi$ variability at the faster frequency. It should be noted that these breakdowns did not result in transitions to the stable symmetric mode range ($-50 < \phi < 50$) because the task instructions required the pairs to resume the original (180°) phase mode if a breakdown occurred (rather than switch to a different phase mode if it felt more stable; cf. Schmidt et al., 1990).

Overall deviation from the intended phase of 180° increased as $\Delta\omega$ deviated from 0 (differences between SC groups are taken up later). This result replicates previous findings that a coupled-oscillator dynamic such as Equation 1 is being assembled to establish between-person rhythmic coordination of limbs (Schmidt & Turvey, 1994). The coupling strength $k$ of this dynamic ($-1.55$), estimated from the data pooled across SC groups, is of the same order of magnitude as that previously observed for between-person rhythmic coupling ($-5$ for Schmidt & Turvey, 1994) but somewhat lower. The difference in magnitude could be attributable to procedural differences—fewer trials per pair means that these participants were less practiced, and fewer pendulum combinations decreased our ability to estimate $k$ by a regression analysis—or to the inclusion of different SC groups from the extreme ends of the scale who, themselves, varied in $k$ (see discussion to follow).

We noted earlier that the effect of $\Delta\omega$ on $\phi$ fluctuations is somewhat anomalous with respect to the prediction from Equation 1. Whereas the coupled-oscillator dynamic predicts that fluctuations should be lowest at $\Delta\omega = 0$ they were, in fact, relatively high at $\Delta\omega = 0$ (pooled over SC groups). A multiple-regression analysis, however, supports an argument (cf. Rosenblum & Turvey, 1988) for two sources of fluctuation in interlimb coordination systems, one at the level of the coupled system (indexed by the location of the $\phi$ attractor) and one at the level of the individual oscillators (indexed by the lengths of the individual pendulums). The former source is the dynamic represented by
Equation 1 and, as expected, fluctuations in $\phi$ are positively related to it. The latter source is the magnitude of the relaxation dynamic assembled to move a component oscillator through its cycle, and fluctuations in $\phi$ are negatively related to it.

With respect to the social variable, breakdowns in phase locking were more prevalent for the homogeneous LL and HH pairs than for the heterogeneous HL pairs. The fact that HH pairs were not the most coordinated dyads is counter to the hypothesis stated in the introduction. Intuitively, we speculated that the degree of between-person coordination established by socially competent individuals would be highest because they should be better able to perceive social affordances and, hence, achieve interaction goals. The present results suggest that high SC in and of itself does not guarantee interactional synchrony; instead, complementary SC levels seem to produce higher degrees of coordination than matched levels. How can this result be understood?

One way of rationalizing the result is to assume that SC might covary with social control or dominance. Social coordination must involve a subtle give-and-take so that the interactants do not work at cross purposes. Under this characterization, social interaction would require both a willingness to give (e.g., follow) as well as an ability to take (e.g., lead) suggesting more successful coordination when the individuals' SC levels are complementary. The assumption underlying this claim is that high-competence individuals' ability (at least in this sample) will compel them to lead, control, or dominate whereas low-competence individuals' lack of skill will compel them to follow, submit, or acquiesce.

In support of this hypothesis, a closer examination of the composition of our participant sample revealed that overall SC scores were most highly correlated with scores on the Social Control subscale ($r = .66$). The fact that this subscale accounted for 44% of the variance (rather than 17% as would be expected with equal weighting of the six subscales) suggests that the type of competence characterizing this sample was leadership or dominance. On this interpretation, homogeneous pairs would be equally dominant. Hence, one might expect to find unreliable responses within these dyads to the perturbations arising at the more difficult, higher frequency, due to either a lack of willingness to take control (LL pairs) or a competition for control (HH pairs). Social dominance by only one of the participants in the HL pairs should lead to more coordinated behavior because the low-competence individual becomes the follower whereas the high-competence individual becomes the leader when a perturbation must be resolved to satisfy the task demand (alternate mode phasing). A similar pattern of dominance and acquiescence has been found in the social coordination of individuals high or low on the Expressiveness scale. In a study by Sullivan (1991) on emotional contagion, subjects who varied in expressiveness were paired into high–high, low–low, and high–low dyads. The strongest effect was for the high-expressive members of the high–low dyads to exert more influence.
on the moods of the low expressives than vice versa. This finding strengthens and replicates the findings of Friedman and Riggio (1981).

This dominance hypothesis is consistent with the conjecture that high-competence individuals are more likely to maintain their own preferred dynamic and low-competence individuals are more likely to be drawn from their preferred dynamic. Although facilitating coordination in HL pairs, these tendencies undermine coordination in homogeneous pairs, at least at the more difficult faster frequency where perturbations to the coordination may result from the similarity of their maintenance tendencies. This interpretation of HL coordination is consistent with a finding in a coordinated writing task involving the variable of handedness: When a breakdown in coordination between the two hands occurred, it was the nondominant hand that switched to the pattern of the dominant hand (Byblow, 1994; Van Riper, 1935).

Do the data of the present study support this conjecture? Two analyses of the HL pairs data were performed to answer this: Given just the physical constraints on the oscillatory dynamic in Equation 1, one would expect that when the $\Delta \omega = 0$ the mean $\phi$ should equal $180^\circ$. Recalculating mean $\phi$ as $\theta_{\text{high}} - \theta_{\text{low}}$, a positive deviation from $180^\circ$ would indicate that high-competence individuals were leading in the cycle in spite of the physical constraints whereas a negative deviation would indicate that the low-competence individuals were ahead in their cycle. The mean $\phi$ of this condition calculated in this way is $182^\circ$. Although this positive deviation is not significantly different from $180^\circ$ ($p > .05$), it indicates that the high-competence individual was slightly leading the low-competence individual in a given cycle. Another test of the relative dominance of the two participants in the HL pairs can be made by comparing their respective fluctuations in periodic timing: Greater fluctuations can be taken as evidence of being more influenced and, hence, less dominant. In accord with this expectation, the low-competence individuals had a higher mean period standard deviation than did the high-competence individuals ($0.125$ s vs. $0.056$ s, $p < .01$). In short, the results of these analyses support the hypothesis that the high-competence participants were showing a greater maintenance tendency and, hence, dominating the coordination pattern.

The social variable SC also interacted with the physical variable $\Delta \omega$. The manipulation of $\Delta \omega$ allows one to ascertain through a regression analysis (a) whether or not stable between-person phase locking can be characterized as a dynamical oscillatory regime and (b) the coupling strength $k$ of the regime. As remarked, the HH pairs were not assembling a coupled-oscillator control structure to produce the stable phase-locking behavior whereas the HL and LL pairs were. The observed covariance of social competence and social control may explain this result as well. Intuitively, by appropriating Equation 1, a person or pair is sharing the control with dynamical principles of self-organization. Hence, a dyad's harnessing of a coupled-oscillator dynamic to guide their movements may require more giving up of active control over the coordination than active maintenance of it. The dominance of the HH pairs
may result in a switching of or fighting for control of the coordination whereas the lower dominance of the LL pairs and reciprocal dominance of the HL pairs may allow the dynamical dyadic synergy to emerge.

Finally, the social variable also seemed to have an effect on the magnitude of the fluctuations of $\phi$. During stable phase locking, the HH pairs produced more fluctuations in $\phi$ at $\Delta\omega = 0$ than did the other two SC groups. This effect may reflect the fact that these pairs had not established a coupled-oscillator dynamic to guide their movements, as discussed in the preceding. But this effect may also indicate which dynamical components were being affected by the HH pairs' competition. Recall that large fluctuations at $\Delta\omega = 0$ can be taken to be a consequence of a relatively greater relaxation dynamic being assembled locally to oscillate the smaller length pendulums. The analyses suggest that this relaxation dynamic is particularly prominent for the HH pairs. The prominence of the relaxation dynamic could be the source of the pairs' inability to cooperate. Oscillators with greater relaxation components have a stronger limit cycle dynamic that makes them resistant to perturbations. Hence, the prominence of the relaxation dynamic may be just that dynamical property that precludes instantiation of the coupled-oscillator regime to guide the coordination. Indeed, the regime in Equation 1 assumes that the component oscillators are purely harmonic and have no relaxation component underlying their motion. Although this may be an idealization for purposes of modeling, wrist-pendulum oscillation has been found to be primarily harmonic (Beek et al., in press). Perhaps in those cases when the oscillation contains a relatively large relaxation component, the coupled-oscillator regime of Equation 1 cannot be established. In other words, the finding that HH pairs seemed to perform the coordination task worse than LL or HL pairs may be just what should be expected if one understands this task not in terms of social cooperation but, rather, in terms of the cooperativities latent within dynamical processes.

Bimanual coordination tasks have been instrumental in bringing phenomena of biological movement under dynamical systems analysis. The wrist-pendulum task, in particular, by allowing easy manipulation of preferred frequencies and driving frequencies, has proven to be a useful tool for examining a variety of implications of dynamical models of coordination. Extending that task from within-person to between-person coordination showed how general the phenomena are, especially with respect to the informational basis for the coordination, be it haptic or optic. The present results extend the usefulness of these techniques for examining the reality of social constructs, with the promise that persisting properties of social interactions can be identified with specific dynamical components.

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