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Effects of Visual and Verbal Interaction on Unintentional Interpersonal Coordination

Michael J. Richardson and Kerry L. Marsh
University of Connecticut

R. C. Schmidt
College of the Holy Cross and University of Connecticut

Previous research has demonstrated that people's movements can become unintentionally coordinated during interpersonal interaction. The current study sought to uncover the degree to which visual and verbal (conversation) interaction constrains and organizes the rhythmic limb movements of coactors. Two experiments were conducted in which pairs of participants completed an interpersonal puzzle task while swinging handheld pendulums with instructions that minimized intentional coordination but facilitated either visual or verbal interaction. Cross-spectral analysis revealed a higher degree of coordination for conditions in which the pairs were visually coupled. In contrast, verbal interaction alone was not found to provide a sufficient medium for unintentional coordination to occur, nor did it enhance the unintentional coordination that emerged during visual interaction. The results raise questions concerning differences between visual and verbal informational linkages during interaction and how these differences may affect interpersonal movement production and its coordination.

Interpersonal interaction often results in the movements of two interactants being coordinated. The dyadically defined goals that intentionally constrain interpersonal interaction are typically responsible for the emergence of this coordination. For instance, when two people are dancing, moving a table together, or walking step-by-step with one another, each individual's behavior is coupled to their partner's so a shared goal can be achieved in a fluid and unperturbed manner. However, although interpersonal coordination is typically understood as intentional, highly task constrained, and sometimes overtly controlled through physical contact, it is also the case that movement coordination can occur unintentionally where the interaction is less physical and more psychological in nature. Accordingly, research has shown how interacting individuals unintentionally coordinate or mimic such behaviors as postures (Bernieri & Rosenthal, 1991; Charney, 1966; Chartrand & Bargh, 1999; LaFrance, 1982; LaFrance & Broadbent, 1976), mannerisms (Chartrand & Bargh, 1999), eating (Johnston, 2002), and facial expressions (Anisfield, 1979; Bavelas, 1986; Bavelas, Black, Lemery, & Mullett, 1987; Field, Woodson, Greenberg, & Cohen, 1982; Meltzoff & Moore, 1977; Provine, 1986; Strack, Martin, & Stepper, 1988).

To a large degree, research on interpersonal movement coordination and mimicry has focused on the relationship between unintentional coordination and social–cognitive variables. For example, a number of researchers found that individuals tend to like others who more often mimicked or produced movements that were similar to their own behaviors (e.g., Bernieri, 1988; Charney, 1966; LaFrance, 1979). Still others have demonstrated that individuals feel more similar to those who they have imitated (Chartrand & Bargh, 1999), that interpersonal coordination is a behavioral manifestation of social rapport (Bernieri, Reznick, & Rosenthal, 1988; Bernieri, Davis, Rosenthal, & Knee, 1994; Bernieri, Gillis, Davis, & Grahe, 1996; Grahe & Bernieri, 1999), or that mimicry reflects a relational or other-directed focus (Cheng & Chartrand, 2003; Lakin & Chartrand, 2003; Sanchez-Burks, 2002; van Baaren, Maddux, Chartrand, de Bouter, & van Knippenberg, 2003). In general, the relationship between interpersonal coordination or mimicry and being other-directed is usually seen as a positive bidirectional relation (Lakin, Jefferis, Cheng, & Chartrand, 2003). That is, such coordination is not only a concomitant of rapport but also causes the person being mimicked to be more helpful and generous to others (van Baaren, Holland, Kawakami, & van Knippenberg, 2004; van Baaren, Holland, Steenaert, & van Knippenberg, 2003). Psychological states such as rapport have been a central focus of mimicry and coordination research, but a number of other cognitive variables have also been explored. For instance, investigators have demonstrated how social stereotypes, cooperative intent, and goal activation impact mimicry (e.g., Bargh & Chartrand, 1999; see Dijksterhuis & Bargh, 2001, and Chartrand & Jefferis, 2003, for reviews).

Social–cognitive psychologists have proposed that unintentional interpersonal mimicry occurs because the mental representations used in the perception of another individual's (or one's own) movement are either strongly linked with the representations involved in producing those movements or are in fact the same

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Michael J. Richardson and Kerry L. Marsh, Center for the Ecological Study of Perception and Action, University of Connecticut; R. C. Schmidt, Department of Psychology, College of the Holy Cross, and Center for the Ecological Study of Perception and Action, University of Connecticut.

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Correspondence concerning this article should be addressed to Michael J. Richardson, Center for the Ecological Study of Perception and Action, Department of Psychology, U-1020, University of Connecticut, 406 Babbidge Road, Storrs, CT 06269-1020. E-mail: michael.richardson@huskymail.uconn.edu

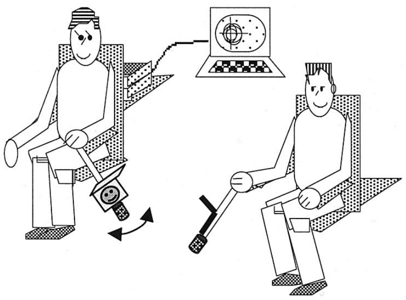
representations (Bargh & Chartrand, 1999; Carver, Ganellen, Froming, & Chambers, 1983; Dijksterhuis & Bargh, 2001; Meltzoff & Prinz, 2002; Prinz, 1987). In other words, drawing largely from William James's (1890) ideomotor theory of action, this cognitive perspective asserts that perceiving an action activates the corresponding mental representations of that action and consequently increases the tendency to perform that action.

Whereas a cognitive perspective may provide a discerning explanation for the occurrence of cognitively mediated interpersonal coordination (unintentional, automatic, or otherwise), this perspective ignores the differences between mimicry and other forms of interpersonal coordination. Mimicry refers to movement replication (imitation) in which two or more interacting individuals perform the same or similar actions (e.g., gestures, mannerisms). Consequently, the majority of research on mimicry relies on nondynamic or aggregate measures that reflect "mutual influence" without necessarily reflecting the "mutual adaptation" in time (Cappella, 1996)—which is argued to be a crucial feature of interpersonal responsiveness (Bernieri & Rosenthal, 1991; Tickle-Degnen & Rosenthal, 1987). A more dynamic aspect of interpersonal coordination involves synchrony or entrainment in which the movements of interacting individuals become organized in time and space (Bernieri et al., 1988; Bernieri & Rosenthal, 1991; Schmidt & O'Brien, 1997; Schmidt & Turvey, 1994). This distinction between mimicry and synchrony was previously drawn by Bernieri and Rosenthal (1991), who used the generic term of *behavioral matching* to refer to mimicry phenomena.

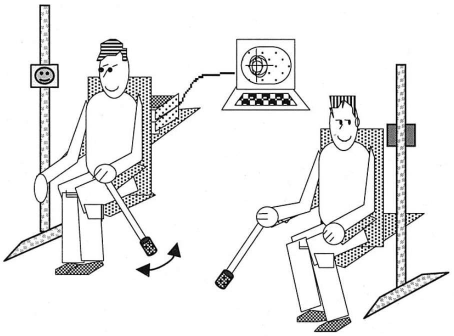
The differences between mimicry and interpersonal synchrony are important because the two phenomena warrant different explanations. For mimicry, similarity in the movements of interacting individuals can be explained using the cognitive explanation of priming in much the same way that priming of schemas affects behavior. An individual's jittery and fidgeting style of movement may prime a construct related to higher arousal states and thus elicit similar kinds of behavior in a perceiver. In that sense, one actor's movement acts as a prime in much the same way that priming an elderly stereotype through exposure to words in an experiment leads participants to walk more slowly after the experiment ends (Bargh, Chen, & Burrows, 1996). Thus, priming explanations for movement imitation or mimicry do not require that movements be organized in time (occur simultaneous with the prime or even after some period of time) but can occur so long as activation of the construct has not diminished sufficiently (Aarts & Dijksterhuis, 2002; Bargh et al, 1996; Dijksterhuis, Spears, & Lepinasse, 2001). On the other hand, neither a social–cognitive nor a socioemotional focus (i.e., that mimicry leads to increased empathy or rapport) offers much assistance in explaining the temporal organization of interpersonal synchrony. In fact, both views are overly focused on the connection between represented perceptual states and isomorphic actions with little attention given to how the movements of two people seem to periodically recur in a correlated fashion.

A more effective way of understanding the temporal correlations of interpersonal coordination is provided by the dynamical systems approach to coordinative behavior. From this perspective, coordinated movements of interacting individuals can be viewed as an entrainment process of biological and behavioral rhythms rather than as merely a consequence of a representational mechanism (Bernieri & Rosenthal, 1991; Newtson, Hairfield, Bloomingdale, & Cutino, 1987; Warner, 1998). This hypothesis assumes that natural human movements occur rhythmically (i.e., they tend to reoccur periodically; Gallistel, 1980) and that coordination is constrained by the same dynamical processes of self-organization that constrain interacting physical oscillators (Kelso, 1995; Kugler & Turvey, 1987). Precedence for this theorizing has come from two sources: first, from research on insect coordination that demonstrates how the synchronized flashing of fireflies is governed by the dynamical entrainment processes of coupled oscillators (Hanson, 1978) and, second, from research on human interlimb coordination that demonstrates how the coordination of intrapersonal rhythmic movements (i.e., bimanual wrist movements of a single person) can also be understood in terms of self-organized entrainment processes of a coupled-oscillator dynamic (Fitzpatrick, Schmidt, & Carello, 1996; Kelso, 1995; Turvey, Rosenblum, Schmidt, & Kugler, 1986).

To evaluate whether interpersonal synchrony could possibly be understood by the same dynamical processes that govern the entrainment of rhythmic limb movements of a single person, researchers have investigated this entrainment hypothesis for visual interpersonal coordination in a series of interpersonal coordination studies (Schmidt, Bienvenu, Fitzpatrick, & Amazeen, 1998; Schmidt, Christianson, Carello, & Baron, 1994; Schmidt & Turvey, 1994) by having pairs of participants intentionally coordinate handheld pendulums (dowels with weights attached to the ends) swung from the wrist (see Figure 1). Using this methodology, which is similar to the one used to investigate interlimb coordination of a single person (Kugler & Turvey, 1987; Turvey, 1990; Riley, Santana, & Turvey, 2001), the authors of these studies



a. Visual and Visual/Verbal Conditions



b. Verbal Condition

Figure 1. Experimental setup for the (a) visual and visual/verbal conditions and (b) verbal condition.

found that the space–time organization of the interpersonal rhythms (the relative phase angle ϕ of the two participants' movements) followed predictions of a coupled-oscillator dynamic (see Appendix), namely, that only inphase (near $\phi = 0°$) and antiphase (near $\phi = 180°$) coordination patterns could be stably maintained (without practice), that the antiphase mode was less stable than the inphase mode, and that the deviation from perfect inphase and antiphase depended lawfully on the degree of inherent frequency difference (manipulated by the difference in length of the two pendulums) of the two oscillatory movements.

This research showed that when two people intentionally coordinate their movements, the pattern of synchrony is governed by very general dynamical processes of self-organization (a coupled-oscillator dynamic) that seem to operate across physical, biological, behavioral, and social scales of nature. It also demonstrates that visual information is a sufficient medium for such a coupled-oscillator dynamic to be sustained. However, the question can legitimately be raised whether these dynamical processes are operating in natural interpersonal coordination. The laboratory task used to investigate interpersonal coordination is two steps removed from natural interpersonal coordination. First, the task requires the participants to intentionally coordinate their movements, and the interpersonal coordination observed in natural interactions is unintended and unnoticed by the interactors. Second, it uses an unnatural stereotyped rhythmic movement (wrist-pendulum swinging) so that the temporal organization of the two movements (phase entrainment) can be easily evaluated by available coupled-oscillator methodologies. Schmidt and O'Brien (1997) adapted the wrist-pendulum methodology to increase its external validity by investigating whether unintentional synchrony would occur if a pair of participants had visual information about each other's movements but had no explicit intention to coordinate. To test this, they had pairs of participants sitting side by side, either looking straight ahead while swinging a wrist pendulum at their own preferred, comfortable tempos or looking directly at each other while maintaining their own preferred tempo.[1] The results indicated that when the individuals in a pair were able to see each other's movements, they exhibited a higher cross-spectral correlation (indicating increased synchrony) than when not looking at each other and had a greater concentration of relative phase angles near 0° and 180°, indicative of a self-organized coupled-oscillator dynamic. Not only do these results demonstrate that interpersonal synchrony can occur unintentionally (i.e., participants were instructed to maintain their own tempo and not entrain), but they also provide clear evidence that visual information can function as a means (a coupling) by which the rhythmic movements of two interacting individuals can become unintentionally coordinated.

Despite the clarity of Schmidt and O'Brien's (1997) findings, however, questions can be raised about whether the findings can be generalized to more natural interpersonal situations. One problem with this study is that Schmidt and O'Brien did not provide a cover story as to why participants should look at the other individual's swinging pendulum. Consequently, individuals might have synchronized with the other's pendulum in response to implied demand characteristics—in spite of the request that they swing at their own tempo. Additionally, the naturalness of the social interaction in which the participants were involved is questionable. For unintentional interactional synchrony to occur, there must be a focal social task to which movements are less focal concomitant. In Schmidt and O'Brien's study, the task—simply looking or not looking while swinging a pendulum at a comfortable tempo—is not very natural or socially interactive. However, such a task is arguably a reasonable starting point for understanding the emergence of interactional synchrony under the most minimally controlled circumstances in which individuals can form a social unit (however minimal). In our view, the minimal circumstances necessary for forming a social unit is for two individuals to be copresent and for an informational linkage to exist between them—in this case, a visual coupling. Clearly, if interpersonal synchrony can occur because of a simple visual coupling, it provides a powerful argument for the self-organized emergence of synchrony.

Obviously, however, there does appear to be a legitimate concern about possible interpretations of Schmidt and O'Brien's (1997) findings and a reasonable interest in also extending it to more natural social situations. A reasonable extension is to add conversation to the interaction. Indeed, language occurs prototypically in social interactions and can be seen as a vehicle by which two or more people produce "joint actions" in order to achieve a mutual goal (Clark, 1996). Moreover, the unintentional linking of one actor's movements with another's is affected by conversation at a great number of time scales—from the coordination of speech and hand gestures that are milliseconds long to cycles of conversation that span about an hour (Davis, 1982). Indeed, a number of psychological studies have demonstrated unintentional between-person postural and gestural coordination during conversation (e.g., Chartrand & Bargh, 1999; Condon & Ogston, 1966; Kendon, 1970; LaFrance, 1982).

However, adding conversation to an experimental investigation of interactional synchrony raises questions about the role language plays in interpersonal coordination. Does it provide a basis for it (i.e., is it sufficient?) or does it just enhance it? Whereas past studies have demonstrated that verbal communication is part of interpersonal coordination, they have not manipulated conversation during the interactions and therefore have not been able to ascertain the degree to which the conversational aspects of the interaction provide or enhance the interpersonal linkage. Because in past research, participant pairs were able to see each other as well as converse, it is hard to ascertain whether or not the coordination was not simply a result of visual information, a plausible possibility given the findings of Schmidt and O'Brien (1997).

A recent study conducted by Shockley, Santana, and Fowler (2003), however, was specifically designed to determine whether conversation is sufficient to entrain the postural movements of two interacting participants. In this experiment, a standing participant performed a verbal problem-solving task either with another participant or with an experimenter. The dyadic task consisted of discussing the subtle differences between two similar cartoon pictures that were placed on wooden stands. Each participant could only see one of the pictures. In different conditions, participants interacted visually and verbally (most natural), interacted just verbally (faced opposite directions), interacted just visually (faced each other but conversed with an experimenter), or did not interact

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[1] Past research by Schmidt and Turvey (1992) has found that even for pendulums of identical sizes, different participants will maintain slightly different tempos.

(control condition; faced away and conversed with an experimenter). In addition to manipulating the interaction medium, the study's researchers also objectively measured the movements of the participants. Movement sensors attached to participants' waists measured the 2 participants' postural stabilizing movements (postural sway). Of interest was whether the two postural sway time series had similar structure—indicating entrainment. The results demonstrated a higher degree of postural entrainment between the participants when they were interacting verbally, trying to solve the problem, regardless of whether visual information about the other person was available. Moreover, having visual information about the other person available by itself (while each participant conversed with an experimenter) did not result in postural entrainment.

These findings suggest that interpersonal postural entrainment is mediated by conversational properties, such as speech rhythms or joint-angle changes that occur because of one's own, or partner's, vocal intensities or gestures (Shockley et al., 2003). Indeed, there are a number of past studies that support this conclusion, where the speaking behavior of individuals itself demonstrates a fair degree of coordination during a conversation. Specifically, speech scientists have demonstrated that interacting individuals tend to converge in dialect (see Giles, Coupland, & Coupland, 1991, for a review), speaking rate (Street, 1984), vocal intensity (Natale, 1975), and pausing frequency (Cappella & Planalp, 1981). It is important to note, however, that the Schockley et al. (2003) study is unique, in that it demonstrates that speaking is a medium by which individuals can unintentionally coordinate their physical movements.

The Shockley et al. (2003) study is also important because it represents a methodological advance in measuring interactional synchrony—one that measures not only linear but nonlinear correlative properties. To measure how the postural movements of the two individuals were correlated in time, the authors used a technique known as cross recurrence quantification analysis (CRQ; Zbilut & Webber, 1992) that objectively measures the degree to which movement patterns converge in time without assumptions of linearity. This ability makes CRQ the ideal tool for analyzing subtle nonlinear couplings that occur between two interacting individuals.

Current Investigation

The present study furthers the test of the dynamical hypothesis for interactional synchrony, namely, that movements between interactors become temporally correlated because they are constrained by the self-organizing principle that governs coupled oscillators. We developed a methodology that integrates aspects of both Schmidt and O'Brien (1997) and Shockley et al.'s (2003) studies, by having 2 participants perform an interpersonal puzzle task (identifying the differences between two cartoon pictures) while simultaneously swinging handheld pendulums. The task was described so that participants perceived the interpersonal puzzle-solving task as the main focus of the study. The cartoon face stimuli, which the participants had to confer about, were attached to the wrist pendulums being swung, and the swinging was described to the participants as simply a motoric distraction task. Participants performed the puzzle task under different information conditions: (a) while interacting both visually and verbally, (b) while interacting verbally but not visually, and (c) while interacting visually but not verbally.

This study will further previous work in two ways. First, it will allow us to further investigate the role that conversation plays in unintentional interpersonal coordination. Shockley et al. (2003) found that verbal interaction is sufficient to create interpersonal coordination in postural sway. We will be able to determine the influence conversation has on the unintentional coordination of overt, intentionally produced rhythmic movements like wrist-pendulum swinging. Wrist-pendulum swinging and postural sway differ substantially in how they relate to language production: Wrist movements are more distal on the body and hence less biomechanically linked to speech production. Consequently, we may not expect conversation to provide a supportive medium for coordination itself. However, because conversation has been found to increase rapport, we might expect conversation with vision to increase the degree of coordination exhibited. A third possibility is that the conversation may function as a distraction and decrease any visual coordination produced. The second way this study will further past research is that it will replicate Schmidt and O'Brien's (1997) investigation of visual unintentional coordination of wrist pendulums and may provide further evidence that just looking at another's movements will cause an interactor to synchronize his or her movements with those of the other. However, this study will use a focal interaction task that is more natural, namely, an interpersonal problem-solving task. This will reduce the demand characteristics of the previous study's focal task (just looking at the other's pendulum while maintaining one's own tempo).

On the basis of past unintentional coordination research (Schmidt & O'Brien, 1997; Schmidt, O'Brien, & Sysko, 1999), we expect the temporal correlation of the movements to be quite weak and the result of a coupled-oscillator dynamic that exhibits not a (strong) phase locking but rather (weaker) phase entrainment of movements. Hence, the movements of the 2 participants will be at different frequencies, each swinging at his or her own preferred tempo. Such weakly coupled movements demonstrate intermittent attraction to coordinated states, referred to by von Holst (1939/1973) as *relative coordination*. Consequently, any entrainment that occurs between participants in the current study will exhibit patterns of coordination tending toward, but still moving between, the two stable modes of coordination of a coupled-oscillator dynamic—0° (inphase) and 180° (antiphase). Moreover, given that the inphase mode of coordination has been shown to be more stable than antiphase coordination, we expect that participants will be unintentionally drawn toward an inphase mode of synchrony more often than to antiphase. (See Appendix for discussion of how these predictions relate to the proposed mathematical mode for interlimb coordination.)

Experiment 1

The first experiment investigated the effect of conversational interaction on unintentional synchrony using a methodology similar to Schmidt and O'Brien's (1997). Similarly, pairs of participants sat side-by-side and swung handheld pendulums about the wrist. For part of the trial, the participants were interacting (experimental trial segments), whereas in other parts, they were not interacting (control trial segments). Different from the previous study, the interaction consisted of completing the interpersonal puzzle task verbally with vision, verbally without vision, or just visually.

Method

Participants. Thirty-six undergraduates from the University of Connecticut participated in partial fulfillment of course requirements. The participants were paired to form 18 participant dyads. This resulted in 8 mixed gender pairs, 4 male pairs, and 6 female pairs. All participants were right handed and had normal or corrected-to-normal vision.[2] Three pairs were eliminated from the data set. One pair was dropped because they did not continuously swing their pendulum during the task. Two other pairs were dropped because the similarity of their natural frequencies resulted in a trivial pattern of coordination. Instructing participants to begin swinging at different times (a procedural weakness that was remedied in Experiment 2) would have obviated this problem.

Materials. Participants sat on chairs 1 m apart, facing the same direction (Figure 1). Each chair had a forearm support attached to the inside of the chair parallel to the ground. This ensured that the handheld pendulums would be swung about the wrist in the sagittal plane and that participants could have an unobstructed view of their partner's pendulum. Two handheld pendulums, each composed of a wooden dowel that was 54 cm in length and that had a 100-g weight attached at the base, were used. An 11 × 10-cm cardboard frame was attached to each pendulum just above the weight to hold the cartoon pictures. The motion of the handheld pendulums was recorded at 30 Hz using a magnetic tracking system (Polhemus Fastrak, Polhemus Corporation, Colchester, VT) and 6-D Research System software (Skill Technologies, Inc., Phoenix, AZ). Two sensors were used to record the angular displacement of each participant's wrist while swinging the pendulum. One sensor was affixed to the pendulum just below the hand and the other was positioned to the forearm approximately 3–4 cm from the hand.

Twelve pairs of cartoon faces (approximately 10 cm × 9 cm) were used as stimulus pictures. Each cartoon picture was constructed from the same template face and had the same facial dimensions. Each face differed in color, number or type of facial features (e.g., nose, hair, or teeth), and type of facial gesture (e.g., smiling or frowning). The pictures were individually displayed (see Figure 1) either on the picture frame at the base of the pendulum (visual and visual–verbal conditions) or at eye level on wooden stands situated 30 cm from the outer arm of each participant chair (verbal condition).

Procedure. Upon arrival, participants were informed that the experiment was investigating interpersonal communication during an interpersonal puzzle task. They were told that they would be required to complete six experimental trials in which they would have to verbally identify as many differences as they could between two cartoon pictures, even though they would only be able to see one picture while their partner viewed the other one. They were also told that they would have to complete a secondary motor task—swinging a pendulum—referred to as a distraction task, at the same time as they were completing the interpersonal puzzle task. Participants were shown an example of a pair of pictures and were informed that they would have 20 s to identify as many of the differences between the two pictures as possible. It was made clear to the participants that the pictures would be independently positioned either on the stand next to them or on their partner's pendulum.

Once they understood how to complete the puzzle task, the participants were then given a pendulum and instructed to hold it firmly in their hands and to swing it so that moving the wrist generated an oscillatory motion of the pendulum from front to back. Participants were instructed to swing their pendulum at their own self-selected tempo, a tempo they found comfortable and could sustain for an extended period of time, and to maintain that self-selected tempo for the entire length of each trial. One after the other, each participant was then given approximately 20 s to practice swinging his or her pendulum. Despite the two pendulums having identical lengths and masses and, consequently, the same natural frequency of oscillation, past research by Schmidt and Turvey (1992) indicated that different individuals tend to swing the same pendulum at slightly different frequencies.

Participants completed six 60-s trials under three different experimental conditions (two trials for each condition). Each trial was completed continuously and contained three 20-s trial segments (participants did not stop between trial segments; rather they made a continuous transition between the trial segments). For the first and third (control) segments, participants were instructed to swing a pendulum from the wrist without verbally communicating or looking at each other. Participants faced the wooden stand positioned parallel to the outer side of each chair away from the other participant. The experimental manipulation occurred during the middle trial segment: In the visual condition, participants silently swung pendulums while looking at the picture positioned on each other's pendulum; in the visual–verbal condition, participants swung pendulums while conversing and looking at the picture positioned on each other's pendulum; and in the verbal condition, participants swung the pendulums while conversing with each other but looked at the picture positioned on the wooden stand placed at the outer side of their own chair. For the verbal and visual–verbal conditions, participants were instructed to verbally identify with their partner as many of the differences between the two pictures during the middle 20 s of the trial. For the visual condition, because they were not allowed to talk until after the trial had ended, participants were asked to study each other's picture during the middle trial segment so they could verbally identify as many of the differences between the two pictures as possible for 20 s after the trial ended. They were told that it was important they study the pictures carefully during the middle trial segment, as they would not be able to see the pictures at the end of the trial. Participants were explicitly reminded just prior to each trial to swing the pendulum at their own self-selected tempo and maintain that tempo throughout the trial. Condition order was counterbalanced across pairs. After completing all six trials, participants were questioned to determine whether they were aware of the study's real purpose, were debriefed, and were thanked for their participation.

Data reduction. For each trial, the middle 15 s of each 20-s trial segment was extracted from the participant's wrist motion time series to avoid transients induced by transitions between the trial segments. Four dependent measures were obtained from these time series: cross-spectral coherence, distribution of relative phase angles, and the two cross-recurrence measures: percentage recurrence and maxline. There was no effect of trial, so the result for each dependent measure was averaged across the two trials of each condition.

The primary indices of coordination used were cross-spectral analysis (Gottman, 1981; Warner, 1998), which uses a linear model to evaluate the correlation of the two time series at different frequencies or across a range of frequencies (Porges et al., 1980) and the distribution of the relative phase angles (ϕ) created by the interacting rhythms exhibited over time. Cross-spectral coherence indexes how correlated two time series are over a range of possible component frequencies and measures the degree of coordination from 0 to 1, with 1 reflecting *complete coherence* (absolute synchrony/phase locking) and 0 reflecting *no coherence* (no phase entrainment/synchrony) at a given frequency. Continuous relative phase is helpful in making inferences about the nature of the processes underlying the coordination, because if the dynamical processes modeled by a coupled-oscillator dynamic is operating, we expect relative phase angles to be distributed near the attractor locations of this model (i.e., 0° difference—inphase—and 180° difference—antiphase).

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[2] Despite the fact that sitting side-by-side meant that participants were using an opposing (perhaps nondominant) hand, the effects of handedness in producing a rhythmic wrist movement have been shown to be minimal and to have little to no effect on whether stable coordination will occur (see Treffner & Turvey, 1995).

The use of a linear model of correlation, however, is not always appropriate for evaluating the relationship between two time series, especially if the relationship is nonlinear or nonstationary (as we expect is often the case with a weak or intermittent coupling). Consequently, because unintentional interpersonal coordination in past research appears to have been weakly coupled, cross-recurrence analysis (Zbilut, Giuliani, & Webber, 1998) will also be used to measure the "correlation" between the two time series. Moreover, it is always prudent to use multiple measures when evaluating such an abstract property of a system (Rangarajan & Ding, 2000). On the basis of the principles of phase-space reconstruction, CRQ requires the embedding of two time series (x and y) in phase space, using surrogate dimensions created using the same time delay in the respective time series (Webber & Zbilut, 1994). Overlap of trajectories [$x(i) = y(j)$ within some radius] in reconstructed phase space counts as recurrence in CRQ. The resulting CRQ statistics of percentage recurrence, which reflects the degree of shared recurrence of the pair's movements (*overlapping points* in phase space), and maxline, which reflects the stability of shared activity over time (convergence of nearby trajectories over time) were used to evaluate the similarity of movement between people at multiple time scales without the assumption of linearity.

Results and Discussion

The current experiment was designed to determine whether and how looking and conversation would influence the unintentional coordination of rhythmic movements of two interacting individuals. To establish whether such coordination occurred, we examined the cross-spectral coherence, distribution of relative phase angles, and degree of shared activity (CRQ) for the trial segment time series of each participant pair. For each type of analysis, the first and third trial segments (the control segments when there was no visual or verbal information linking participants) were compared with the second trial segment (the trial segment when participants were interacting). The degree of entrainment was examined to establish whether the coordination was different in kind and magnitude across the three conditions (visual, verbal, and visual–verbal).

Cross-spectral coherence. The cross-spectral coherence was submitted to a 3 × 3 repeated measures analysis of variance (ANOVA) with independent variables of condition (visual, verbal, visual–verbal) and trial segment (first, second, third). The analysis yielded a significant main effect for trial segment, $F(2, 28) = 6.94$, $p < .01$; a marginal effect for condition, $F(2, 28) = 2.65$, $p < .09$; and a significant Condition × Trial Segment interaction, $F(4, 56) = 3.27$, $p < .02$. As can be seen in Figure 2, for the visual and visual–verbal conditions, participants exhibited more coherence in the second trial segment than in the first and third trial segments. For the verbal condition, however, participants exhibited the same level of coherence across all three trial segments. Post hoc tests revealed an increase in coherence between the first and second trial segments for the visual (.28–.56) and visual–verbal (.26–.52) conditions ($p < .05$), but no difference between any of the trial segments (.32, .31, and .26, respectively) in the verbal condition ($p > .05$). In addition, no significant difference was found between the second and third (visual = .43; visual–verbal = .37) trial segments, indicating that participants continued to be slightly coordinated following their interaction.

Like the findings of Schmidt and O'Brien (1997), the differences in cross-spectral coherence show unintentional synchrony between participants when visual information about their partner's wrist movements was available. However, the results demonstrate that the wrist movements of a pair did not become correlated when the participants were verbally interacting. This is reflected by the fact that there was no increase in coherence while participants interacted verbally (without vision) during the second trial segment of the verbal condition. Moreover, this suggests that the increase in coherence exhibited by participants while interacting in

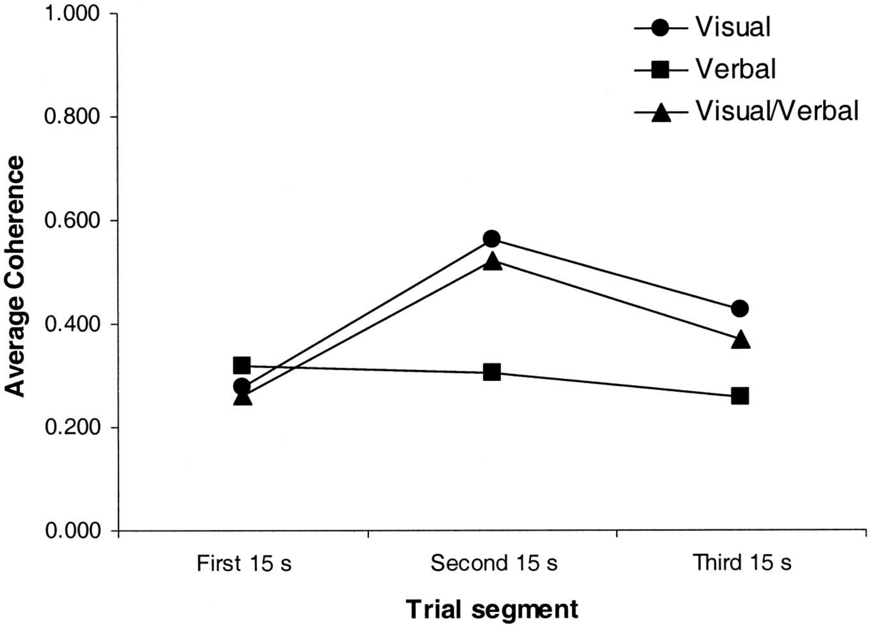

Figure 2. The average cross-spectral coherence for the three information coupling conditions across the three trial segments. s = second.

the visual–verbal condition was simply due to the visual coupling and not the verbal interaction.

Continuous relative phase. To identify whether the increase in cross-spectral coherence for the second trial segment of the visual and visual–verbal conditions points to a pattern of coordination indicative of the coupled oscillator dynamic, we determined the distribution of relative phase angles across nine regions of relative phase between 0° and 180° by calculating the frequency of occurrence of the relative phase angle in each of these regions for each trial segment of each condition. If a coupled-oscillator dynamic is present, we expect to find higher relative phase angle counts near the attractor states of this dynamic, namely, 0° and 180°. The counts were then submitted to a 3 (condition) × 3 (trial segment) × 9 (phase region: 0°–20°, 21°–40°, . . . 61°–180°) repeated measures ANOVA. There was a significant main effect for phase region, $F(8, 84) = 13.92$, $p < .01$; a significant Phase Region × Condition interaction, $F(16, 336) = 5.04$, $p < .01$; a significant Phase Region × Trial Segment interaction, $F(16, 336) = 9.08$, $p < .01$; and a significant three-way interaction between phase region, trial segment, and condition, $F(32, 672) = 4.60$, $p < .01$.

For the visual condition, as can been seen in Figure 3, the first and third trial (control) segments exhibited relative phase angles evenly distributed between 0° and 180°. For the second visual condition trial segment, however, participants exhibited a strong tendency to swing their pendulums at relative phase angles near 0°, suggesting that participants were unintentionally pulled toward an inphase mode of coordination. A similar distribution of relative phase is present in the visual–verbal condition, with first and third trial segments exhibiting a flat distribution of relative phase angles and a greater number of relative phase angles near 0° in the second trial segment. In contrast, the distribution of relative phase angles for the verbal condition did not change across the three trial segments. These results are consistent with participants being attracted toward the most stable mode of a coupled oscillating regime (inphase) when they were entrained (as determined by cross-spectral coherence) in the visual and visual–verbal conditions and suggest that an oscillatory dynamic synchronized the dyad's movements only when participants were visually interacting.

Example relative phase time series for the three different conditions are shown in Figure 4. For the first trial segment of all conditions, the participant pair cycled through all possible relative phase relations, as expected when two oscillatory systems are uncoupled and moving at their own independent frequency. This pattern continues for the second and third trial segment of the verbal condition, with the pair's movements not relaxing to the modes of coordination predicted by the coupled-oscillator model. For the visual and visual–verbal conditions, however, once the

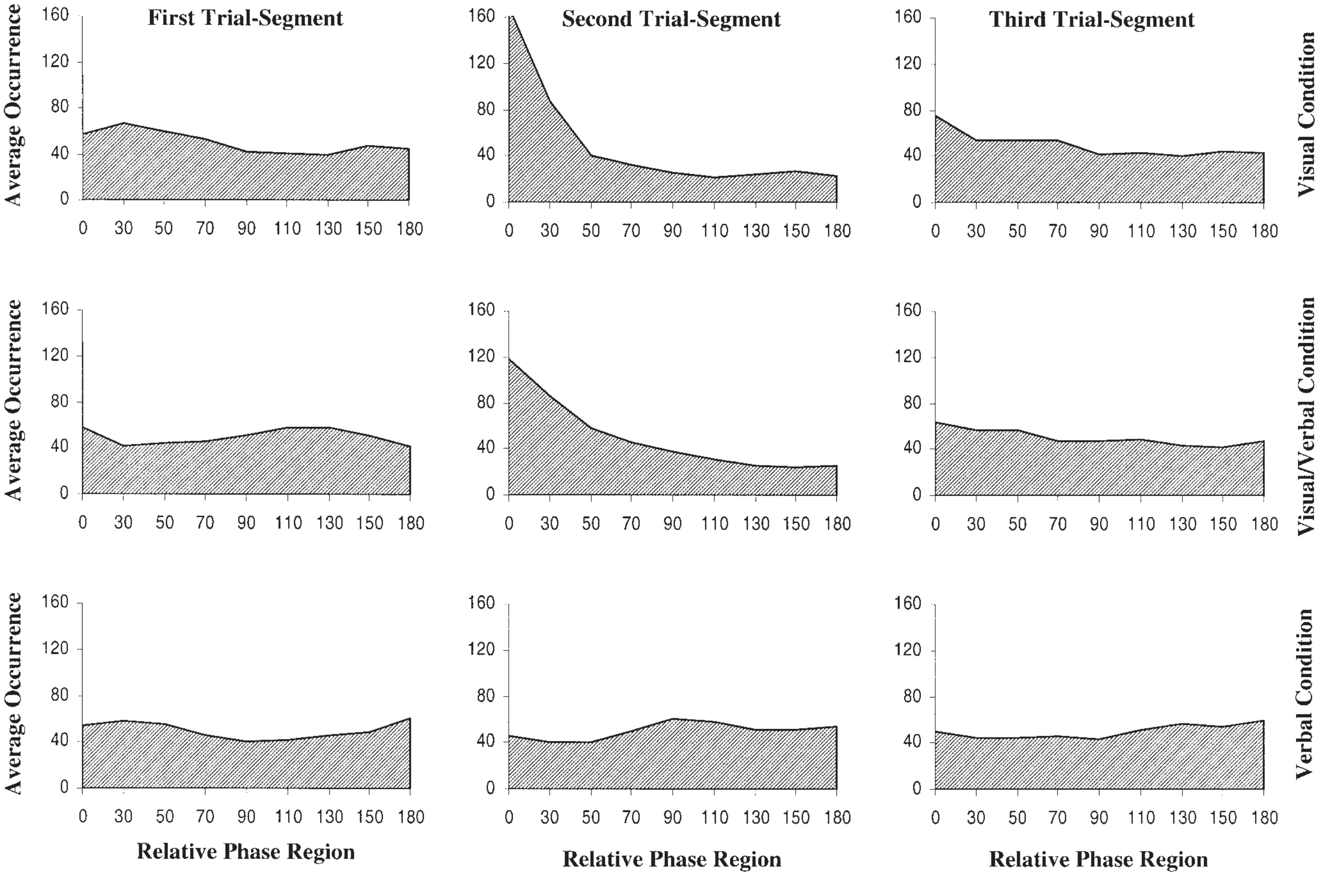

Figure 3. The distribution of relative phase angles for the three information coupling conditions across the three trial segments.

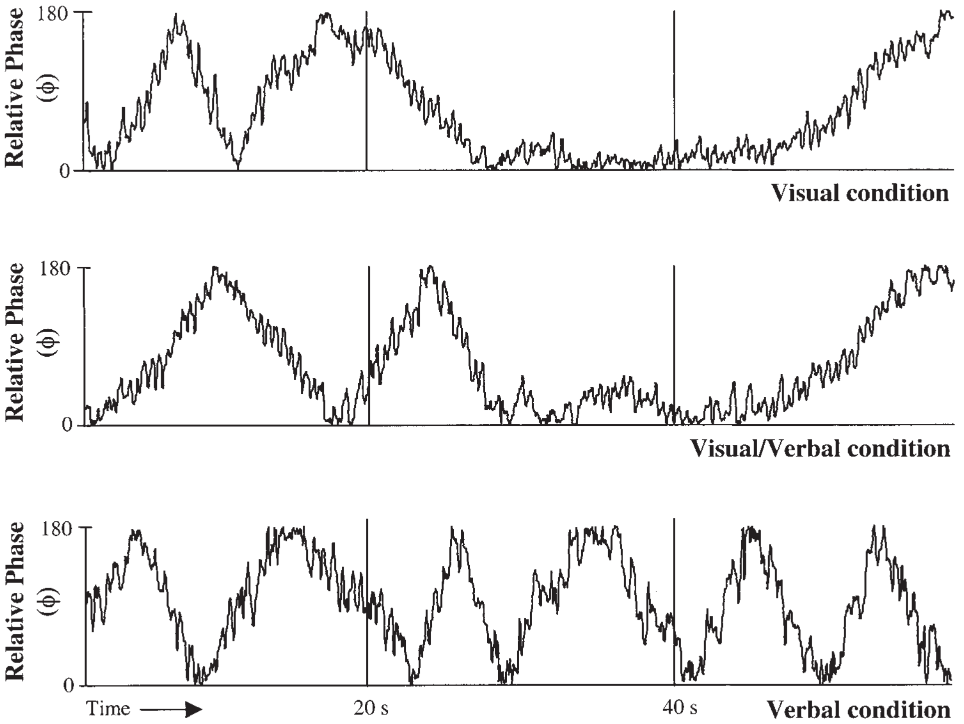

Figure 4. Three continuous relative phase trial time series showing the change in the relative phase angles between the participants of Pair 10 over the length of an experimental trial from each of the three information coupled conditions. s = second.

participants in the pair are coupled visually, they relax to a state of equilibrium around 0° and remain there in a relatively stationary manner well into the third trial segment, at which point their movements become uncoordinated again and the relative phase angle begins to change continuously over time.

Cross-recurrence quantification (CRQ). Using CRQ, Shockley et al. (2003) found evidence for unintentional postural entrainment of individuals who were verbally linked—CRQ is sensitive to subtle nonlinear structure in time series. In light of this, CRQ was used to analyze the data of this experiment in order to determine whether any weak, nonlinear coordination of movements occurred between participants when verbally interacting. The resulting measures of percentage recurrence and maxline were subjected to separate 3 (condition) × 3 (trial segment) repeated measures ANOVAs.

The analysis of percentage recurrence (i.e., percentage convergence of points in phase space) yielded a main effect of condition, $F(2, 28) = 4.22$, $p < .03$, and a marginal interaction between condition and trial segment, $F(4, 56) = 3.06$, $p < .08$. As can be seen from Figure 5, no increase in percentage recurrence was evident for the second trial segment (5.57%) of the verbal condition but rather a slight decrease was evident from first (6.08%) and third (6.31%) segments, indicating that the trajectories of a pair were less overlapped during verbal interaction than when not interacting. In contrast, there was an increase in percentage recurrence (greater overlap of trajectories in phase space) during the second trial segment of the visual and visual–verbal conditions, as opposed to the first trial segment when participants were not interacting. This increase was more pronounced for the visual than for the visual–verbal condition, with an increase from 6.21% to 7.38% for the visual condition but only a 6.27%–6.56% increase for the visual–verbal condition. It is interesting to note that the percentage recurrence for the third trial segment (7.27%) of the visual condition was the same as that found for the second trial segment, indicating that the pair member's trajectories continued to share a greater amount of phase space directly after interacting.

For maxline (stability of shared activity), the ANOVA revealed a significant main effect of condition, $F(2, 28) = 4.06$, $p < .05$, and trial segment, $F(2, 28) = 3.34$, $p < .05$, as well as a significant Condition × Trial Segment interaction, $F(4, 56) = 4.17$, $p < .01$. As Figure 5 shows, the pattern of results is similar to that of percentage recurrence. In particular, the results for maxline show that the wrist movement trajectories of a given pair of participants diverged less over time when they were interacting in the visual and visual–verbal condition but not for the verbal condition. Indeed, as for percentage recurrence, the trajectories of participants in a pair appeared to diverge more over time when they were merely verbally interacting. Also consistent with the findings of percentage recurrence was the fact that there was less divergence over time in the third trial segment of the visual and visual–verbal conditions.

The overall pattern of results from the CRQ analysis is consistent with the findings of coherence and continuous relative phase, indicating that a visual coupling is required for the unintentional coordination of wrist movements. In addition, CRQ seems to be reinforcing that which is observed in the linear measures, namely,

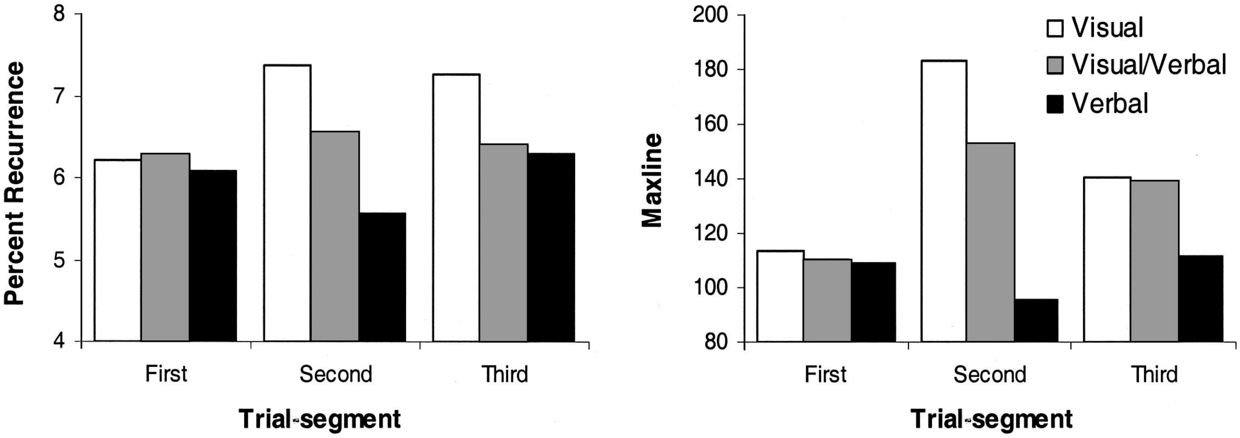

Figure 5. The average percentage recurrence and maxline for the three information coupled conditions across the three trial segments.

that verbal interaction does not enhance the unintentional coordination of wrist pendulums but appears to decrease the amount of synchrony observed, perhaps by causing participants to attend less to the wrist movement task. Indeed, this may explain why the analysis of cross-spectral coherence and continuous relative phase found pair member's movements to be less entrained when they were interacting both visually and verbally as opposed to when they were simply interacting visually. In other words, despite the fact that verbal interaction provides for a more naturalistic situation, these results appear to indicate that conversational behavior may undermine the stability of the unintentional synchrony brought about by vision.

Experiment 2

Experiment 1 demonstrated that unintentional coordination between interacting individuals when visually coupled could occur, replicating the findings of Schmidt and O'Brien (1997). Counter to Shockley et al. (2003), Experiment 1 found no evidence to suggest that verbal interaction (conversation) has a constructive influence on unintentional synchrony of rhythmic wrist movements. In contrast, the results of Experiment 1 appear to suggest that verbal interaction may in fact be detrimental to the stability of unintentional synchrony brought about by vision. One possible reason for the lack of increased entrainment when participants were verbally interacting, however, is that a longer time scale may be required for verbal interaction to mediate unintentional coordination. For example, participants in the Shockley et al. experiment interacted verbally for a period of at least 2 min, as opposed to only 20 s in the current study. Work by Davis (1982) and Hayes and Cobb (1982) has demonstrated that the unintentional linking of one actor's movements with another's is often observed at longer time scales during conversation. In addition, given that perceiving and producing speech (verbal gestures) is less directly linked to the production of rhythmic arm movements than it is to postural sway (i.e., speech gestures produce postural adjustments both prior to and during speech), one might expect that any influence of verbal interaction may be weaker on the coordination of wrist movements. Consequently, a weaker coupling, such as this, may require a longer time to be established. To address this possibility, we used in Experiment 2 a similar methodology to Experiment 1 but had participants interact for a longer period, namely, for 2 min.

Another reason for using longer trials is to see whether the visual unintentional coordination found in Experiment 1would be stable over the long term. Given the weakness of the observed visual coordination, the question is whether participants are able to regain coordination if it is lost. In other words, do the wrist movements of participants ever diverge once coordinated, and if so, do they ever converge again?

Method

Participants. Eighteen undergraduates from the University of Connecticut participated in partial fulfillment of course requirements. The participants were paired to form 9 participant dyads. This resulted in 4 mixed gender pairs, 2 male pairs, and 3 female pairs. All participants were right handed and had normal or corrected-to-normal vision.

Materials. The same materials and experimental setup used in Experiment 1 were used for Experiment 2 except for different cartoon pictures. To make sure the participants would verbally interact for a full 2 min, we constructed more complicated cartoon pictures. Three pairs of cartoon pictures were generated so that each pair of pictures had exactly 10 differences. The differences were less obvious than in Experiment 1. For example, in one pair of the new pictures, faces differed in that one had seven and one had eight freckles. Four pairs of participants were used to test the complexity of the pictures. Those pilot participants identified no more than 7 picture differences while they verbally communicated for 2 min.

Procedure. The longer trials required a change in the structure of the trials.[3] Participants completed four trials: one control and three experimental trials. For the control trial, participants swung handheld pendulums about the wrist for 2 min facing away from each other (i.e., with no visual or verbal interaction and no visual picture to look at). For the three experimental trials, the participant pairs completed an interpersonal puzzle

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[3] Despite the fact that participants in Experiment 2 completed 2-min trials, which were twice as long as the trial length used in Experiment 1, swinging a handheld pendulum for 2 min is not unusually long for such tasks and is not of sufficient length to be fatiguing.

task visually, verbally, or visually and verbally while swinging handheld pendulums. The interpersonal puzzle task was similar to that used in Experiment 1 and consisted of pairs of cartoon pictures that were individually displayed either near the base of a participant's handheld pendulum (visual and visual–verbal conditions) or at eye level on wooden stands situated next to each participant (verbal condition). Participants were required to verbally identify as many of the differences as they could between the picture they viewed and the picture their partner viewed either during the trial (verbal–verbal visual) or for 2 min after it ended (visual condition). For exploratory purposes, the responses of the dyads were audiotaped in order to assess performance.

As in Experiment 1, participants were told that the experiment was investigating interpersonal communication during an interpersonal puzzle task. Once it was clear that participants understood how to complete the puzzle task, they were given a practice period of approximately 20 s. Then, they completed the control trial and performed the three experimental trials. We used a Latin-square ordering across participant pairs. Participants were reminded just prior to each trial to swing the pendulum at their own self-selected tempo and to maintain that tempo throughout the trial. To eliminate the trivial coordination that occurred between the two pairs dropped from analysis in Experiment 1, we made sure that participants were told to start swinging at different times. After completing all four trials, participants were questioned about their opinion on the study's purpose, were debriefed, and were thanked for their participation. Analyses of cross-spectral coherence, continuous relative phase, and CRQ (percentage recurrence and maxline) were performed on the two 2-min time series of a participant pair for each trial.

Results and Discussion

Experiment 2 was designed to investigate whether unintentional coordination occurred between verbally and visually interacting individuals at time scales greater than those of Experiment 1's trial length (20 s). In particular, the current experiment examined whether verbal interaction could operate to facilitate the unintentional coordination between interacting individuals given a longer time scale (minutes rather than seconds) and whether the unintentional coordination between visually coupled individuals remained stable across time. To accomplish these aims, we compared the degree and stability of entrainment between participants in the four conditions (control, visual, verbal, and visual–verbal).

Cross-spectral coherence. The cross-spectral coherence was submitted to a one-way repeated measures ANOVA. The analysis revealed a significant effect of condition, $F(3, 24) = 8.88, p < .01$, with participant pairs exhibiting a moderate degree of coherence for the visual (.51) and visual–verbal (.33) conditions and very low coherence for the verbal (.06) and control (.05) conditions (see Figure 6). Post hoc analysis revealed that the level of coherence was significantly greater for the visual and visual–verbal conditions as compared with the verbal condition (both ps $< .03$) and as compared with the control condition ($p < .03$ and $p < .05$, respectively). No difference was found between the verbal and control conditions ($p > .05$), whereas the difference between the visual trial and visual–verbal trial was found to be marginally significant ($p = .07$).

These results are similar to those found in Experiment 1: The time series of participants were more correlated when visual information about their partner's wrist pendulum was available but uncorrelated during verbal interaction and in the control condition. Also like Experiment 1, the current findings appear to indicate that the unintentional synchrony exhibited by participants while interacting in the visual–verbal trial was due to visual, and not verbal, interaction. It is interesting to note that the overall magnitude of coherence was less than that observed in Experiment 1. It was drastically reduced for the visual–verbal, verbal, and control conditions by about 20%. The visual condition coherence was reduced less (only 5%). This suggests that participants exhibited a less stable pattern of coordination in the current experiment than during the relatively short interaction times of Experiment 1 and that in

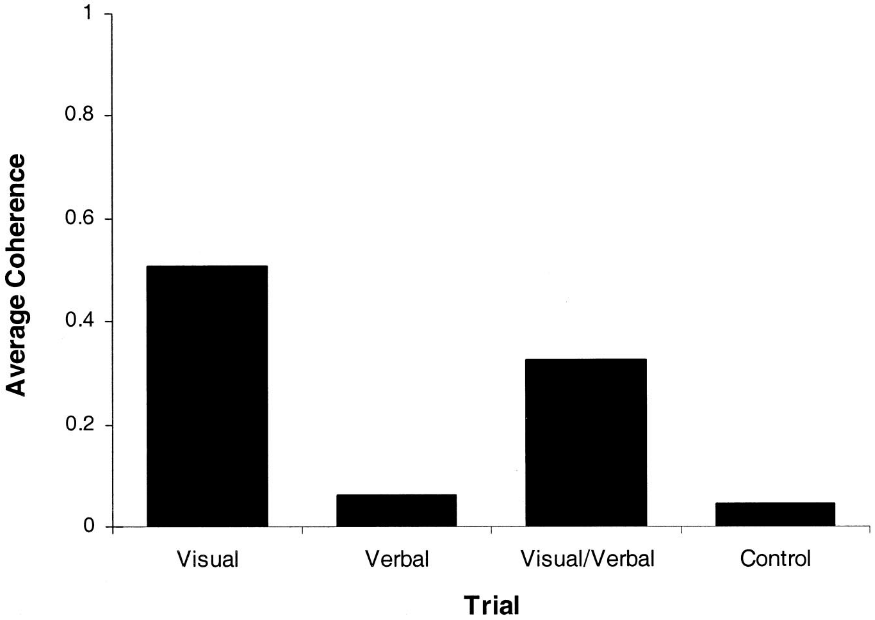

Figure 6. The average cross-spectral coherence for the control condition and the three information coupling conditions.

order to get a true picture of the stability of the interpersonal interaction, a longer observation time should be used.

Continuous relative phase. As in Experiment 1, the distribution of relative phase angles across regions of relative phase between 0° and 180° was determined by calculating the frequency of occurrence of the relative phase angle in each of the regions. These frequencies were then submitted to a 4 (condition) × 9 (phase region: 0°–20°, 21°–40°, . . . 161°–180°) repeated measures ANOVA. There were significant main effects for condition, $F(3, 24) = 805.20$, $p < .01$, and phase region, $F(8, 64) = 10.57$, $p < .01$, and a significant Phase Region × Condition interaction, $F(24, 192) = 1.88$, $p < .01$. As can be seen in Figure 7, although participants exhibited an even distribution of relative phase angles for both the verbal and control trials, participants in both the visual and visual–verbal trials exhibited a tendency to swing their pendulums at relative phase angles near both 0° and 180°. That participants in the current experiment were attracted toward (and moved between) both coordination modes predicted by a coupled-oscillator dynamic and in conjunction with the lower coherence levels reported above indicates relative (less stable) rather than absolute (more stable) coordination in these longer trials. Inspection of the time series for the visual and visual–verbal trials confirmed this, with participants initially being drawn toward inphase coordination and then alternating between antiphase and inphase modes of coordination.

Cross-recurrence quantification (CRQ). CRQ was used to determine whether with these longer trials, the various interactional conditions affect the nonlinear relationships of the rhythmic movements between the interacting participants. Percentage recurrence (overlapping points) and maxline (stability of shared activity) were analyzed separately in one-way repeated measures ANOVAs. The analysis of percentage recurrence was not found to be significant, $F(3, 24) = 2.15$, $p = .12$. However, as shown in Figure 8, participant pairs exhibited equal amounts of percentage recurrence for the control, visual, and visual–verbal conditions but less for the verbal condition. The relatively small percentage recurrence for the verbal condition is similar to the findings in Experiment 1 and suggests that verbal interaction may actually decrease the amount of coordination that emerges between individuals interacting visually. The analysis of maxline (stability of shared activity) was also found to be marginally significant, $F(3, 24) = 2.75$, $p = .07$, and reflected a slightly different pattern than percentage recurrence. The visual and visual–verbal maxline tended to be greater, indicating that participants converged for longer periods of time in these conditions, as opposed to the control and verbal conditions. This pattern is consistent with the coherence and continuous relative phase analysis, reflecting the relatively stable unintentional coordination exhibited by participants in the visual and visual–verbal conditions.

With the longer trial times in Experiment 2, the two CRQ measures seem to be uncovering different aspects of the data (as opposed to Experiment 1 in which both measures showed the same pattern). Percentage recurrence appears to demonstrate the deleterious effect that verbal interaction has on the convergence of the time series (i.e., less than the control condition) but does not find the amount of convergence in the visual condition to be different from that of the no interaction condition. Alternatively, maxline reveals that the relationship between the two time series in the visual and visual–verbal interactions are more stable than the control condition. Recent work by Pellecchia, Shockley, and Tur-

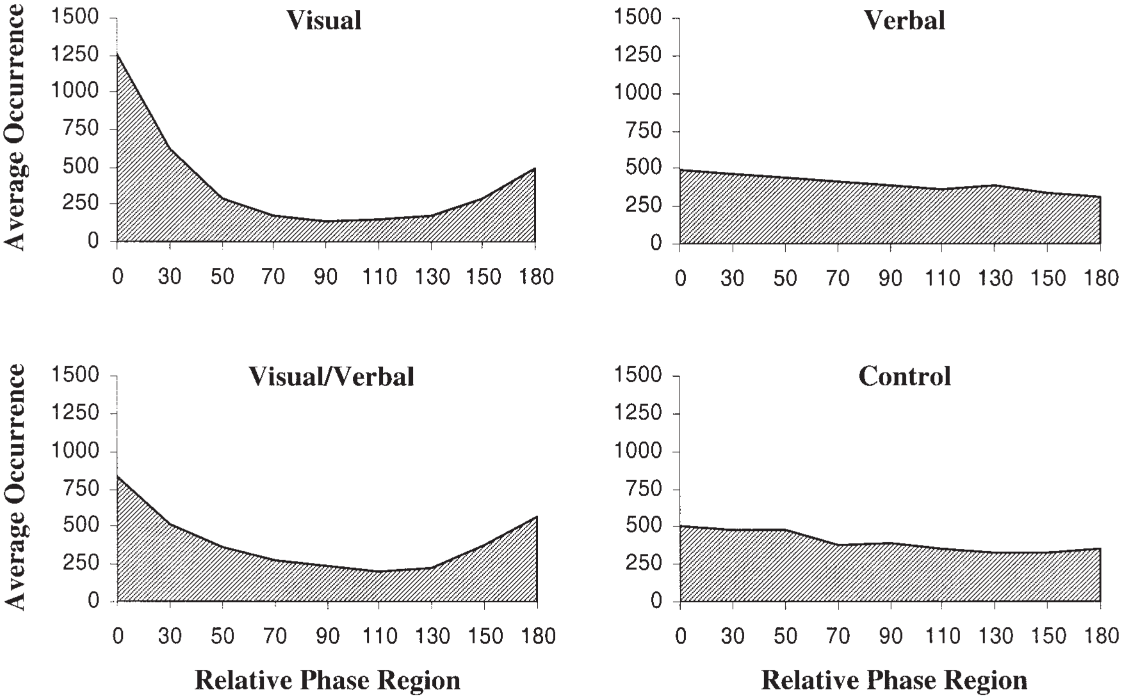

Figure 7. The distribution of relative phase angles for the control condition and the three information coupling conditions.

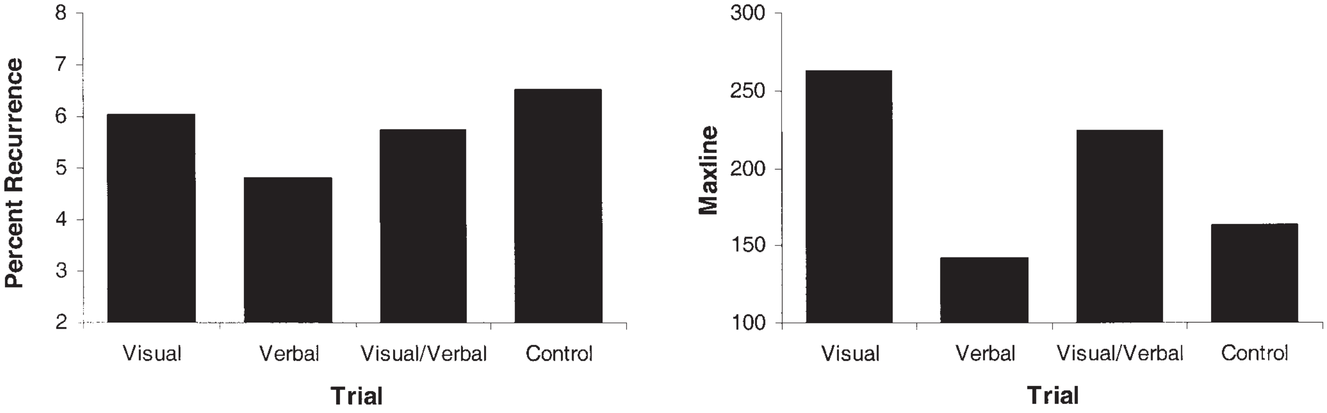

Figure 8. The average percentage recurrence and maxline for the control conditions and the three information coupled conditions.

vey (in press) indicates that percentage recurrence and maxline are sensitive to different aspects of an oscillatory system's dynamics. In particular, they suggest that maxline relates to the strength of the system's attractor or pattern of coordination, whereas percentage recurrence is related to the level of noise in the system. If this is the case, then the present somewhat contradictory pattern of results can be interpreted as follows. Maxline appears to be isolating the degree to which the 2 participants are attracted toward a stable mode of coordination, whereas percentage recurrence reflects the level of noise or perturbations in the system—independent of whether the pairs' movements were coordinated (coupled to each other) or not.

Work by Pellecchia et al. (in press) has also demonstrated that increased cognitive effort during interlimb coordination produces a decrease in percentage recurrence (i.e., an increase in noise) without affecting maxline (attractor strength). They claimed that cognitive effort affects the magnitude of the system's internal noise (the strength of Q in the coupled-oscillator dynamic equation in the Appendix). The more cognitive activity or effort required by a person during a coordination task, the noisier the pattern of coordination that results. With respect to the current findings, the puzzle task was designed to be more difficult in Experiment 2 than in Experiment 1 to ensure that participants interacted verbally for the full length of the 2-min trials. Therefore, the decrease in the percentage recurrence, for the visual and visual–verbal conditions of Experiment 2, when compared with the result of Experiment 1, may simply reflect the increased noise due to the increased task difficulty (and, consequently, cognitive effort).

Task performance. Owing to a malfunction in the voice recording equipment, one pair's performance data were not recorded. Consequently, performance data (number of differences correctly identified between the cartoon pictures) were analyzed using the data from 8 participant pairs. On average, participant pairs identified 4.1 (SD = 1.4) differences between the two cartoon pictures. Differences in performance between the visual, visual–verbal, and verbal conditions were compared using a one-way repeated measures ANOVA. A significant difference was found between the conditions, $F(2, 14) = 3.99$, $p < .05$, with participants identifying more differences in the verbal condition ($M = 5.13$, $SD = 1.28$), than in the visual ($M = 3.75$, $SD = 1.84$) or the visual–verbal ($M = 3.44$, $SD = 0.64$) conditions. This is not surprising, as it indicates that participants performed better when the cartoon picture was stationary rather than moving at the end of their partner's pendulum.

For those conditions in which coordination occurred, the visual and visual–verbal conditions, the number of differences identified by a pair and degree to which the pair's movements were coordinated (indexed by their cross-spectral coherence) were correlated but not significantly ($r = .32$, $p = .20$). However, the effect was moderate and positive, indicating that participants performed better on the interpersonal puzzle task when more unintentional coordination occurred.

General Discussion

Movement coordination is often a necessary occurrence for interpersonal interaction to be successful, where one's intention to coordinate with another individual is explicitly guided by a common goal. However, interpersonal coordination is not always intentional and can emerge between interacting individuals even when the dyadic goal guiding an interaction does not demand such coordination (Davis, 1982). The current study sought to uncover the degree to which visual and verbal interaction constrain and organize the rhythmic limb movements of coactors. In both experiments, pairs of participants completed an interpersonal puzzle task while simultaneously swinging a handheld pendulum at a self-selected tempo. Although both experiments provide definitive evidence that visual interaction (information) can unintentionally couple the rhythmic wrist movements of interacting individuals, no evidence was found to suggest that the verbal interaction (conversation) either supports, or enhances, the unintentional synchrony of visually coordinated rhythmic wrist movements.

Visual Interaction and Unintentional Interpersonal Rhythmic Coordination

The results of the cross-spectral coherence analysis and the CRQ analysis in both experiments indicated that the wrist movements of participants became entrained when visual information about their partner's movements was available (Figures 2 and 6), despite our instructing participants to maintain their own tempo throughout the trial. The coherence values near .5 in both experiments are similar to those reported by Schmidt and O'Brien (1997) for unintentional visual coordination. These magnitudes demonstrate that visual information between the two oscillatory systems only establishes a weak coupling and that the unintentional coordination was not absolute and phase locked but rather relative coordination characterized by phase wandering. The analysis of continuous relative phase further substantiated the relative coordination nature of the unintentional visual synchrony. The distributions of relative phase demonstrate that all relative phase angles were visited (Figures 3 and 7). It is important to note, however, that the concentrations of phase angles around 0° and 180° indicate that the coordination was attracted to the phase angles associated with the attractors of the coupled-oscillator dynamic when visual information about one's partner's movement was available. In particular, the results of Experiment 1 demonstrated that at the onset of visual interaction, participant pairs were typically attracted to an inphase mode of coordination (0°). The results of Experiment 2 demonstrated that, over longer time scales, however, visual interaction resulted in coordination near both inphase and antiphase modes as predicted by the dynamical model with weak coupling strength (see Appendix).

This replication of Schmidt and O'Brien's (1997) work is important because the internal validity of the previous study was questionable. Specifically, the Schmidt and O'Brien experiment did not use a dual task method and a cover story, meaning the possibility remained that the coordination observed was a consequence of participants' responding to a perceived task demand (i.e., figuring that the experimenter wanted them to coordinate). The current studies were methodologically superior in this regard, by having participants actually complete an interpersonal task and converse with one another. Postexperimental interviews demonstrated that all of the participants were surprised that the current study was investigating the coordination of their limb movements; further, none of the participants were aware that they had altered their tempo in any way, and the majority of the participants indicated that they were oblivious to the fact that their movements had become more coordinated with their partner. Whereas one may posit that participants simply swung in unison to facilitate task performance, this possibility does not detract from the fact that the current results provide evidence that unintentional interpersonal coordination occurs in an emergent fashion from the circular flow of (visual) information between the two interacting individuals and that the coordinated state has a dynamical patterning as predicted by the coupled-oscillator dynamic. Nevertheless, to counteract the possible confounds of forcing people to attend to their partners' movements, researchers should conduct subsequent experiments so that the rhythmic movements are more peripheral to the task, thereby providing a more stringent test of unintentional coordination.

Verbal Interaction and Unintentional Interpersonal Rhythmic Coordination

Collectively, the cross-spectral coherence, continuous relative phase, and CRQ analysis from both experiments indicate that verbal interaction as it occurred in the current study neither operates as a facilitating medium for the unintentional coordination of rhythmic wrist movements nor enhances the unintentional coordination brought about by visual information. This was illustrated most clearly in Experiment 2, where both the verbal and control conditions resulted in coherence values that were not significantly different from zero. Moreover, the degree of cross-spectral coherence, percentage recurrence, and maxline exhibited by pairs when interacting both visually and verbally demonstrated that conversational interaction was not only unable to bring about the unintentional coordination of rhythmic movements but slightly decreased, rather than increased, the level of unintentional coordination between individuals when visual information was available.

These results are counter to those of Shockley et al. (2003), who found that the postural sway of interactants only became entrained when conversing and that the coordination of sway was not increased when the interactants were able to see one another. It is interesting to note that the current findings and those of Shockley et al. represent a double dissociation—postural sway is coordinated interpersonally given a verbal but not a visual interaction, whereas rhythmic limb movements are coordinated interpersonally given visual but not a verbal interaction. Indeed, one impetus for the present study was an interpretation of Shockley et al. that was based on social psychological studies of interactional synchrony, mimicry, and rapport. Thus, the current investigation tested the prediction of a strong interpersonal effect of conversation, namely, that the movements of people in conversation would become more synchronized. The present results, however, demonstrate that there are limits to the tendency of conversation to facilitate unintentional interpersonal coordination (even if it does result in higher levels of rapport) and that visual information by itself can be a medium for interpersonal synchrony.

Clearly, there are a number of differences between Shockley et al.'s (2003) study and the current experiment that need to be explored to determine why divergent results were found. Most obvious is the difference in the kind of movements exhibited by the effector and the degree to which verbal interaction affects this movement. In the current study, the participants produced sinusoidal movements, which are larger, more regular, intentional, and less natural than the postural sway movements examined by Shockley et al. Conversation's ability to synchronize the movements of interactants appears to be affected by these differences. In particular, postural sway is a whole body movement and is mechanically linked to elements of the speech apparatus, whereas wrist movements are distal and relatively isolated from mechanical disturbances caused by speaking. Consequently, one might explain the difference in results by interpreting the interpersonal entrainment of postural sway as being a speech epiphenomenon: By completing an interactional task together, the speech of two individuals is coordinated in terms of conversational characteristics (e.g., turn taking, speaking the same words); thus, the mechanical disturbances of speech on postural sway will likewise be coordinated (as well as any body parts linked to such disturbances). Indeed, given that postural sway operates to facilitate the completion of suprapostural tasks (Riccio & Stoffregen, 1988; Riley, Stoffregen, Grocki, & Turvey, 1999), any changes in the structure or stochastic variability of an individual's postural trajectory will be determined by the suprapostural task currently being undertaken by the individual—in this case, speaking. Moreover, although postural changes brought about by a suprapostural task change the structure of a postural trajectory and increase its stochastic variability (Balasubramaniam, Riley, & Turvey, 2000; Riley & Turvey, 2002; Stoffregen, Smart, Bardy, & Pagulayan, 2000), suprapostural tasks have also been shown to increase the level of determinism (structure) in a postural times series (Balasubramaniam et al., 2000). In the case of interpersonal conversation, this increased level of variability and structural determinism would occur for both individuals and would result in the postural trajectories of each individual being more similar than when not conversing. The same argument cannot be applied to rhythmic movements, however, given that they are highly nonstochastic and locally constrained. In fact, any stochastic variability (deterministic or otherwise) added to a stationary (nonstochastic) rhythmic movement would only operate to decrease the periodic structure of those movements. The CRQ results of Experiment 2, when compared with those reported by Shockley et al., may be indicative of this reasoning, in that for postural movements, percentage recurrence appears to be isolating coordination as a shared increase in deterministic variability (due to conversation), whereas this same increase in variability is being isolated by percentage recurrence as noise, detrimental to the coordination of overt rhythmic movements.

Alternatively, the difference between the present results and those of Shockley et al. (2003) may be related to the fact that visual and verbal information are different in kind and might only operate to couple specific movements rather than movements in general. One difference between the two kinds of information is that visual interaction produces information that is far more continuously available compared with verbal interaction. When individuals were visually coupled in the current study, there was a continuous flow of information through the interpersonal system that would engage a participant's attention toward their partner's movements, whereas verbal information occurred in semiperiodic bursts, with participants conversing with their partner in alternation. Perhaps more important is that, although both types of information were essential for completing the interpersonal puzzle task, most likely, only the visual information specified the movements of the pendulums directly. The visual information about another's rhythmic movement while swinging a pendulum is clear and highly salient. In contrast, visual information about another's postural movements is subtle and less apparent and might account for why visual information is sufficiently strong enough to couple rhythmic movements but not postural movements. The content of the conversation, however, did not contain information about the pendulums' movements. That is not to say that paralinguistic auditory patternings do not contain rhythmic information but rather that this information perhaps does not affect or relate to the patternings of rhythmic wrist movements. In addition, whereas previous research would suggest that participants in the current study converged in speaking rate (Street, 1984), vocal intensity (Natale, 1975), and pausing frequency (Cappella & Planalp, 1981), the current findings indicate that this interpersonal coupling may be too weak to coordinate the rhythmic movements of the two individuals or simply occurs independently from unintentional rhythmic coordination. As we remarked above, how such linguistic patterns may be related to postural sway is easier to see than how they might relate to pendulum swinging given the mechanical linkages between the speech apparatus and the postural system.

It might also be argued that the specific conversation that occurred during the interactional task did not facilitate interpersonal coordination because it was more sterile and socially trivial than many social interactions and consequently did not focus the interactors toward the interpersonal or relational level. Some (but not all, e.g., Chartrand & Bargh, 1999) conversational paradigms used in previous research on interpersonal mimicry and coordination have been inherently relational and have led some to suggest that mimicking only occurs as a result of having a relational focus (Sanchez & Burks, 2002). Past research has used tasks in which pairs of participants discuss marital conflict (Gottman & Levenson, 1985; Julien, Brault, Chartrand, & Begin, 2000; Levenson & Gottman, 1983), debate about a topic they disagree on, or simply try to get to know the other person (Bernieri et al., 1994; Bernieri et al., 1996). However, whereas this need for relational focus may be needed to facilitate between-person coordination in research on mimicry and rapport, it is important to note that the same interactional task as the one used in this study was used to facilitate conversation between people in the Shockley et al. (2003) study, in which interpersonal coordination was observed. Moreover, although it is true that the current study used a more socially sterile task, we do not believe that it was completely nonrelational or inherently self-centered. The fact that it did operate to connect people as a social unit by conversing with one another is evidence of this. Furthermore, one needs to appreciate that the aim of the current study was to investigate interpersonal coordination in a context containing the minimal conversational conditions for forming a social connection. In this light, we believe the current conversational paradigm is appropriate.

Implications for Understanding Interpersonal Coordination

The current results suggest that when people visually interact with one another, a coupled-oscillator dynamic emerges, unintentionally organized by the constraints of the interpersonal task and specific to the dyadic unit that comprises the interaction. In other words, an interpersonal attractor emerges that creates interpersonal synchrony during the successful achievement of a mutual, between-person goal. Such results suggest an important alternative to previous means of examining cooperative dyadic interaction. To date, the only approaches for explaining interpersonal coordination (in the form of mimicry) require highly cognitive, individual-level processes that are mute on the temporal correlation inherent to coordination and the informational constraints under which productive movement coordination can emerge. Furthermore, such approaches, which draw heavily on mental constructs as the mechanism, are not able to make specific predictions about the types of coordinated patterns that should occur between interacting individuals. In contrast, the dynamical systems approach offers a means of explaining how interpersonal coordination (in the form of synchrony) is naturally self-organized from structured informational couplings, as well as predicting the manner and type of coordinated movements patterns that emerge, both spatially and temporally (Marsh, Richardson, Baron, & Schmidt, 2003).

It is interesting to note that the current findings raise questions about whether mimicry phenomenon should be used to depict the general case of interpersonal coordination. Bernieri (1988) and Bernieri and Rosenthal (1991) have raised a similar point previously, arguing that mimicry should be distinguished from movement synchrony. Clearly, mimicry is a form of interpersonal coordination; however, it seems more appropriate to consider mimicry as a special case of interpersonal coordination, where coordination contains temporal correlations but perhaps at a scale beyond those that can be effectively measured with current methods. It may prove to be the case that the same dynamical constraints and informational couplings that operate to synchronize and entrain rhythmic movements will also operate to coordinate the discrete gestures, such as foot shaking, more typical of mimicry research. Furthermore, investigating mimicry phenomena from a dynamical systems perspective would shed a great deal of light on the degree to which cognitive versus informational mechanisms play a causal role in interpersonal interaction, coordination, and rapport.

The current study also highlights the most minimal conditions necessary for rhythmic coordination to occur between two individuals: mere interactional presence, mere sufficient visual information about the other person's movement. To find that synchrony occurs when the task is not explicitly social in its relations (where rapport should necessarily be an underlying purpose) and, more important, that conversational interaction does not necessarily enhance interpersonal coordination, is powerful evidence of its pervasiveness—especially given how the movements of the interactors became synchronized during such a brief interpersonal task. The fact that conversation in the context of the current interpersonal task did not enhance unintentional coordination suggests that although conversing with another individual may produce increased levels of rapport, this does not necessarily mean one should expect more unintentional coordination. Indeed, the current findings suggest that minimal visual information about another who is present is the necessary and sufficient condition for rhythmic coordination to occur. That is not to say that the current findings suggest that conversation creates less rapport and, therefore, less coordination. Rather, the results suggest that conversation may simply focus one's visual attention toward a specific other, thereby mediating attention toward the visual couplings that allow for interpersonal rhythmic coordination to occur. Engaging in a conversation with another, copresent individual typically means having that individual within one's visual field of view.

Conclusions

This study investigated the role that visual and verbal interaction play in the emergence of unintentional interpersonal synchrony. To date, researchers have typically confounded visual and verbal engagement by having people complete some shared communication task in the presence of one another. Other than the current study and the work by Shockley et al. (2003), no other research on interpersonal coordination has manipulated visual and verbal interaction independently. The results of the current study on the interpersonal coordination of rhythmic limb movements replicate those of Schmidt and O'Brien (1997) but indicate that verbal interaction or conversation does not facilitate the coordination of rhythmic limb movements. Why verbal interaction supports postural but not rhythmic limb movement entrainment is still unclear. The two kinds of entrainment differ in terms of effector systems (torso vs. limb) underlying them as well as the kind of movements involved (stochastic vs. periodic). The effects of these different properties need to be investigated in future experiments. Additionally, the results of the current study (in particular, those of relative phase) provide further evidence for approaching interpersonal interaction as a self-organizing phenomenon that displays properties of dynamical systems. A coupled-oscillator dynamic represents the dynamical organizing processes that have been used to model the stable modes of intentional interlimb coordination within (e.g., Haken, Kelso, & Bunz, 1985) and between (e.g., Schmidt et al., 1998) individuals. The current study highlights that the very same dynamical strategy that informationally constrains individual and intentional interpersonal actions also operates to constrain the unintentional interpersonal coordination observed here.

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Appendix

The entrainment process in both intra- and interpersonal interlimb coordination has been modeled using a motion (differential) equation that represents the relative phase angle (ϕ) formed between the two movements (which indexes where one rhythm is in its cycle relative to the other):

$$\dot{\phi} = \Delta\omega - a \sin \phi - 2b \sin 2\phi + \sqrt{Q}\zeta.$$

In this equation, ϕ is the rate of change of the relative phase angle formed between the two oscillators, $\Delta\omega$ is an index of frequency competition between them (the difference between the oscillators' inherent uncoupled frequencies, $\Delta\omega=\omega_1-\omega_2$), a and b are coefficients whose magnitudes govern the strength of the between-oscillator coupling, and ζ is a Gaussian white noise process dictating a stochastic force of strength Q (Haken, Kelso, & Bunz, 1985; Kelso, 1995; Kelso, DelColle, & Schöner, 1990; Schöner, Haken, & Kelso, 1986). Similar equations have been used to model the entrainment process in firefly flashing (Hanson, 1978; Strogatz, 1994) as well as cockroach locomotion (Foth & Graham, 1983), the coordination of breathing and sucking in infants (Goldfield, Schmidt, & Fitzpatrick, 1999), and central pattern generators at the neural scale (Stein, 1974).

Stable interlimb coordination (absolute coordination; von Holst, 1939/1973) will occur when ϕ is zero. These attractor states emerge when ϕ is equal to 0° or 180°—when the interlimb coordination is inphase (same parts of the cycle at the same time) or antiphase (opposite parts of the cycle at the same time). Such phase-locked states only emerge when the coupling strength of the dynamic (dictated by the coefficients a and b) is strong enough to overcome magnitude of $\Delta\omega$, the inherent differences in the frequencies of the two oscillators. When the coupling strength is not strong enough to produce phase locking, no stable phase angle will emerge but the oscillations will still be coordinated because they are still attracted to 0° and 180° (Kelso, 1995; Kelso & Ding, 1994; Zanone & Kelso, 1990). Such phase entrainment is known as relative coordination (von Holst, 1939/1973). Both absolute and relative coordination have been observed in intra- and interpersonal interlimb coordination. However, because the coupling strength is weaker in unintentional interpersonal coordination, relative coordination dominates. Hence, by the dynamic systems hypothesis, the temporal correlatedness of natural interpersonal coordination is a form of relative coordination.

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