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Social Connection Through Joint Action and Interpersonal Coordination

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Abstract

The pull to coordinate with other individuals is fundamental, serving as the basis for our social connectedness to others. Discussed is a dynamical and ecological perspective to joint action, an approach that embeds the individual's mind in a body and the body in a niche, a physical and social environment. Research on uninstructed coordination of simple incidental rhythmic movement, along with research on goal-directed, embodied cooperation, is reviewed. Finally, recent research is discussed that extends the coordination and cooperation studies, examining how synchronizing with another, and how emergent social units of perceiving and acting are reflected in people's feelings of connection to others.

Keywords: Joint action; Social coordination; Synchrony; Social affordance; Cooperation; Embodiment; Social embedding; Ecological; Dynamical

1. Introduction

The papers in this special issue cover an array of perspectives on joint action. In particular, the papers provide a good grounding in how higher-level approaches that involve centralized processes or cognition can explain joint action (Bekkering et al., this issue, pp. 340–352; Carpenter, this issue, pp. 380–392; Sebanz & Knoblich, this issue, pp. 353–367), and the role of language in joint action as well (Brennan & Hanna, this issue, pp. 274–291;

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Galantucci, this issue, pp. 393–410; Garrod & Pickering, this issue, pp. 292–304; Shintel & Kesar, this issue, pp. 260–273). In our paper, we focus instead on the fundamentals of describing the *behavior* that is joint action—what is the informational basis for engaging in joint action, what are the conditions under which joint action emerges for socially embedded individuals, and what kinds of patterns of behavior are possible. Finally, we focus on our most recent research regarding the psychological consequences of such patterns, particularly for the emergence of social connectedness.

One overarching motive here is to provide an orientation to joint action that best fits with the embodied-embedded movement in psychology (Brooks, 1991; Clark, 1998; Hutchins, 1995; Semin & Smith, 2008). This new wave in psychology finds us seeking to bridge the gap between our goals—to have a psychology that takes seriously that our brains are embodied and our bodies are embedded in a world (particularly, a social niche)—and the methods of cognitive science that historically have followed from traditional views of cognition. Much excellent work in psychology has been done on the cognitive side of the equation, but the new emphasis on embodiment means that there remain significant constraints on knowing ''outside the head'' that are underexplored. To have a more complete understanding of joint action, we need to explore more deeply the information that is available to make joint action possible as well as how the effectors of the body self-organize according to the dynamics of movement.

Our starting assumption about joint action is that we want an account that fits with views on embodied cognition. The traditional views of cognition see the ''mind/brain as an organ for building internal representations of the external world. By performing internal computations over these representations, the mind/brain comes to a decision about what actions are appropriate'' (van Dijk, Kerkhofs, van Rooij, & Haselager, 2008, p. 299–300). Alternatively, an embodied-embedded view of cognition suggests that the brain plays a more supportive role. Such a role is exemplified in the principle of ''behavior before brain'' (van Dijk et al., 2008). Cognitive processes operate in *service* of behavior; the evolutionary development of cognition was not to direct and simulate (re-present) the world to the mind but originally developed out of the need to coordinate and integrate increasingly complex behavioral repertoires that extended in scope across time and space. A better metaphor for the brain is a ''traffic facilitator,'' helping to ''sustain the necessary conditions for the relevant interaction between body and world to take place'' (van Dijk et al., 2008, p. 309)—not directing behavior but instead biasing the system toward selecting certain environment-evoked behaviors in one's behavioral repertoire over others.

It is in large part *because* we move (and thus must seek what we need to survive and to procreate) that a cognitive system emerged. A good illustration of this is the example of the seasquirt discussed by Glenberg (2008, p. 44). The sea squirt has a brief existence as a tadpole with motion, ability to detect light, and a brain and primitive spinal cord. Once it attaches to a site and thereafter ceases moving, it no longer needs a brain, and it ingests it. In a real sense, the behavior of an organism (and so too, we believe, the coordinated behavior of multiple organisms) has primacy over the emergence of a brain to coordinate such behaviors. The ecological account we present here on joint action is not one that assumes that we are creatures as uninteresting as the sea squirt and that our advanced cognitive processes and language abilities are irrelevant to what is interesting about humans. Rather what is of particular interest to us is in finding a way to bridge that gap between basic movement and perception processes and the concomitant or consequent psychological cognitive states that make coordinating with others of such particular import.

In our view, there are many circumstances in which individuals spontaneously are pulled into the orbit of another's incidental movements, and there are many circumstances where the environmental constraints, or the limitations of our own autonomous action, mean that coordinated joint action comes into being. We think that systematically exploring the informational basis for this emergence, and the dynamics that can allow the self-organization of coordinated action to occur is worthy of study not because we think it implies humans are creatures without intention and mental states but rather because research demonstrates just how integrally intertwined *all* body systems (brain, sensory, psychological, perception, movement) are when engaging in joint action, and that a theory of the dynamics of self organization is needed to understand the complexity of such interacting components.

Despite the physical separateness of our bodies from other bodies, this social pull is as fundamental and essential to functioning in an environment as the coordination that occurs within components of our body. Individual components of movement systems, whether within-body or across bodies, have huge potential variation for movement when considered in isolation, and yet each component, in actual motion is involuntarily and effortlessly interconnected to other elements within a system, to jointly constrain each of the elements. The movements that are possible for an individual limb, *when considered in combination with the motion of other limbs*, is surprisingly restricted. As a novice drummer realizes, there are patterns of movements that are nearly impossible without training, even though technically such combined behavior should always be possible, if each element were examined in isolation. As Schmidt and Richardson (2008) put it, the dynamical perspective makes the prediction that there are some ''dances we cannot do''—whether those dances be alone or with another individual.

This is not to say that the same dances that solo actors and coordinated actors do are identical, it would be uninteresting if no new capabilities for action occurred for those in joint action than solos. At each new level of analysis beyond individual behavior, such as a jointly acting dyad, a small workgroup, or a multilevel corporation, new behavioral organization, new possibilities for action emerge. However, the dynamical, ecological perspective explicitly makes testable predictions that certain patterns of behavior should be demonstrated on all levels—certain patterns should appear, and others should be nearly impossible. We argue that the answer to why our possibilities for moving and for completing actions are so jointly constrained requires understanding the dynamical laws that govern action systems of the body, the coupling of perception and action, and the coupling of person to environment.

The ecological and dynamical systems perspective on solo perception and action has been highly generative over the last 30 years (see, for example, reviews by Warren, 2006; Kelso, 1995; Fajen, Riley, & Turvey, in press; Thelen & Smith, 1994; Turvey, 1990; Turvey & Carello, 1986). A considerably narrower range of research, however, has pursued the implication of grounding the individual within a *social* niche (Baron, 2007; Good, 2007; Heft, 2007; Marsh, Richardson, Baron, & Schmidt, 2006a; Schmidt, 2007). Just as the picking up of information about our environment is fundamental to the performance of action—with seeing of obstacles in our way and continuously adjusting our motion telegraphed across our body—so too, we argue, is an individual in a social context fundamentally constrained by the picking up of information about others' incidental movements and intentional actions. Recognizing that our movements and actions in the world are as constrained by others as, within our body, implies (a) a universality of dynamical principles that unify components in a system—they are true for social as well as for nonsocial action, (b) that linkages are not simply mechanical, but can be informational—that what we take in with a look (or other modality) can affect our behavior as strongly as a mechanical force, and (c) how others ''moor'' us in space and time define's the frames of reference for our past, present, and future behavior.

In the section below we first discuss the implications of findings from 20 years of research on interpersonal synchrony (e.g., Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007b; Schmidt, 1989; Schmidt, Bienvenu, Fitzpatrick, & Amazeen, 1998; Schmidt, Carello, & Turvey, 1990; Shockley, Baker, Richardson, & Fowler, 2007; for a review, see Schmidt & Richardson, 2008) and more limited ecological research on cooperation (Richardson, Marsh, & Baron, 2007a) for social connection with others. Then we discuss very recent research explicitly designed to test hypotheses regarding how bodily synchrony and physical cooperation can serve as the basis for the emergence of sociality.

2. Past research

2.1. Social synchrony

An ecological and dynamical perspective allows for rather precise predictions about the conditions under which individuals will be better able to coordinate their movement with others, and what features of a situation will exert a pull to cooperate with others in completing some task. Researchers have used rhythmic movements that can be effortlessly sustained (swinging a hand-held pendulum-like stick with a weight at the end, rocking in a rocking chair, walking on a treadmill) or aperiodic, highly stochastic, and visually subtler movement (postural sway) as paradigms for examining the dynamics of interpersonal coordination (see Fowler, Richardson, Marsh, & Shockley, 2008; Schmidt & Richardson, 2008; van Ulzen, Lamoth, Daffertshofer, Semin, & Beek, 2008). Movement is tracked by magnetic sensor systems (or force plates) continually during an interaction (i.e., 60 or more times per second), and linear (e.g., spectral) or nonlinear (e.g., cross-recurrence) analyses yield relational measures that quantify the degree of temporal coordination of a pair's movement during the interaction. Presumably, the pull to such a coordinated state tells us something about the most minimal socioemotional connectedness of a pair. For instance, extensive previous research on mimicry and observer-rated synchrony suggests that mimicry and apparent synchrony are associated with greater rapport between pairs (Chartrand & Jefferis, 2003).

Research that objectively quantifies temporally coordinated movement, however, makes a plethora of novel predictions about precisely when and how such behavioral coordination should emerge—and thus, presumably, when socioemotional connectedness should emerge. Although extensive research has verified predictions regarding the circumstances under which the coordination of behavior should emerge, only recently have the socioemotional consequences of such coordination been explored. Our methods for exploring this use motion sensors to examine the near-sinusoidal interpersonal rhythmic coordination of movement that is described by a motion equation known as the HKB equation (Haken, Kelso, & Bunz, 1985; also see Kelso, 1995 and Schmidt & Richardson, 2008, for details). The HKB equation makes clear predictions about the kinds of rhythmic coordination that can and cannot be sustained. If an individual is rocking in a chair, their oscillatory movement back and forth can be portrayed as a sinusoidal wave with the rocking frequency being faster for a heavily weighted chair than with no weight underneath (like an inverted pendulum, see Richardson et al., 2007b). The HKB equation predicts that coupling of any two oscillating systems with similar frequencies should yield two types of stable patterns—''in-phase'' (where both chairs are forward and back at the same time) and ''anti-phase'' (where one chair is maximally forward when the other is maximally backward). If oscillators are coupled more weakly (e.g., two people have only peripheral visual information about the other's movement), they will spend less time in these stable states than when there is stronger coupling (e.g., when the two people have focal visual information about the other's movement). Research confirms that the HKB equation not only holds for intentional coordination of limbs but for spontaneous or uninstructed interpersonal coordination as well (Richardson, Marsh, & Schmidt, 2005; Richardson et al., 2007b; Schmidt & O'Brien, 1997). Although individuals' movements in these experiments were not in lock-step (continually entrained), there was relative coordination (von Holst, 1939). That is, participants moved in and out of coordination but spent significantly more time in in-phase or anti-phase behavior than in noncoordinated states.

A variety of other predictions of the HKB equation have also been found to hold for intentional and spontaneous coordination of rhythmic movement (but see van Ulzen et al., 2008). When two individuals rock in chairs or they swing hand-held pendulums that do not match in natural frequency (i.e., there is what is termed ''detuning'' of the coupled oscillators), there is less coordination overall. Moreover, the coordination that does occur requires great difficulty to achieve; such coordination is also less stable, with the faster pendulum or chair leading the other (Amazeen, Schmidt, & Turvey, 1995; Richardson et al., 2007b; Schmidt & Turvey, 1994). In addition, interpersonal research supports the HKB prediction that in-phase is a state that pairs are more strongly attracted to than anti-phase. Thus, if a pair is in anti-phase coordination, increasing the frequency of their movements will lead them to shift to in-phase coordination, whereas the reverse shift never spontaneously occurs (a phenomena termed ''hysteresis'') (Schmidt et al., 1990, 1998). The shift from in-phase to anti-phase exhibits typical features of a nonlinear transition between modes in dynamical systems. Namely, there is a sudden shift to a new state of the system once a point of ''criticality'' is reached, which is immediately forewarned by a period of increased fluctuations and critical slowing.

Internal timekeeper (or ''internal pattern generator'') approaches have also been developed that can explain the occurrence and differing stability of in-phase and antiphase coordination that occurs in intentional, within-body coordination (e.g., Ivry & Richardson, 2002; Semjen & Ivry, 2001). The key difference relative to our perspective is that alternative approaches posit that internal timekeepers or representations of timed movement generate internal patterns that are similar to or are ''ideal'' characterizations of the timing and form of the behavioral patterns seen. Essentially, this isomorphism at the neuron-anatomy level is argued to be the causal explanation for the behavioral patterns observed.

It is not clear, however, how these accounts explain *spontaneous* coordination patterns (of in-phase, anti-phase) that emerge both in interpersonal coordination and when solo actors respond to an environmental stimulus (e.g., Lopresti-Goodman, Richardson, Silva, & Schmidt, 2008; Schmidt, Richardson, Arsenault, & Galantucci, 2007). Moreover, such constructivist perspectives imply that separate explanations will be needed for unintentional within-person patterns, interpersonal patterns (e.g., accounts that rely on mirror neuron system, Gallese, Keysers, & Rizzolatti, 2004; Rizzolatti & Craighero, 2004), and person–environment patterns (which could not rely on mirror neuron explanations). But the considerable research demonstrating that couplings that underlie the stabilities of intra-, interpersonal, and environmental coordination are all informational (perceptional) runs counter to that assumption (e.g., Bingham, 2004; Meschner, Kerzel, Knoblich, & Prinz, 2001; Roerdink, Peper, & Beek, 2005; Schmidt et al., 1998, 2007; Wimmers, Beek, & Van Wieringen, 1992). Thus, we argue that our perspective is more parsimonious not only given the considerable computational load that centralized cognitive mechanisms, common codes, or neural simulation explanations of rhythmic coordination entail but also because our perspective predicts the common patterns observed across perception-action systems of different scales (solo, solo-environmental, joint action). It seems more likely to us, therefore, that the centralized, microscopic, neural, or cognitive processes that are involved in coordinated perceptual-motor behavior emerge as a consequence of the same natural laws that self-organize and constrain observed macroscopic behavior and thus also require adopting a non-egocentric animal-environment approach (Kelso, 1995; Richardson, Marsh, & Schmidt, in press; Turvey, 2005; Turvey & Fonseca, in press). (Also see Meschner et al., 2001; Tognoli, Lagarde, DeGuzman, & Kelso, 2007, for examples of how a dynamical understanding of rhythmic coordination can help guide hypotheses about the neural and/or perceptual-motor mechanisms that might underlie rhythmic coordination.)

2.2. *Cooperative social action*

A second major area of our research examines ''embodied cooperation,'' which arises when two co-present, individuals in motion coordinate their goal-directed actions. We call this embodied cooperation to contrast with the methods of traditional game-theory approaches to cooperation, which examine strategic decisions made to cooperate or to defect (Axelrod, 1984; Axelrod & Dion, 1988; Thibaut & Kelley, 1959). Game theory approaches do not require individuals to have bodies, to be able to move and detect information about another's movement, or even be co-present with another individual (indeed one might be cooperating/competing against a computer). Such cooperation is a top-down cognitive judgment rather than an emergent process that comes about from embodied individuals who are embedded in a physical and social environment. Studying emergent, embodied cooperation requires that individuals act within a real ''surround'' with features (constraints and opportunities) that are detectable with our perceptual systems (i.e., are not mere constructions of our minds, or ''social situations'' understood metaphorically).

The embodied cooperation paradigm was motivated by the intuition that the presence of another person extends the action possibilities (''affordances'') that are possible for the individual. Just as a tool can extend our capabilities quantitatively (lift larger objects) so might becoming a social unit with another individual extend our action possibilities—qualitatively as well as quantitatively. If it is valid to conceptualize two people coming together in a ''joint perception-action system'' as a new entity with new abilities, the emergence of such a social synergy should be predictable using affordance theory (Gibson, 1977, 1979; Marsh, Richardson, & Schmidt, 2006b; Marsh et al., 2006a; Richardson et al., 2007a).

The term ''affordances'' was coined by Gibson in his ecological theory of perception, which emphasized the mutuality of individuals and the environment. Mutuality means that the perceiving and acting capabilities of an animal, such as vision and walking, will, by necessity, be complementary to surfaces and objects in the world. For example, solid surfaces in an animal's niche exist that are sufficient to support walking of creatures of that weight. Implied as well is that moving will have functional utility—that, unlike many plants, the animal must move in order to seek out food and mates. The ecological perspective goes still further, however, to posit that values and meanings, the valenced possibilities for action in the environment, are directly perceived by individuals in that environment. Affordance theory predicts that there are detectable informational invariants in the various low energy fields that influence our sensory systems (e.g., the optic array for the visual system) that ''are related at one extreme to the motives and needs of an observer and at the other extreme to the substances and surfaces of a world'' (Gibson, 1979, p. 143). Affordances, from this perspective, reflect the fit between the perceiver and the environment.

Both affordances (possibilities for autonomous or joint action) and dynamics are critical concepts that guide our embodied cooperation paradigm. For instance, cooperation's emergence displayed dynamical features comparable to what we found in social synchrony research, namely, hysteresis. That is, whether a pair cooperated or not under the same exact environmental constraints was in part a function of their immediate ''history'': whether their trajectory had been one of continual cooperation or solo action. But interestingly, the research suggests that cooperation in such contexts is a stronger attractor than solo action (R. W. Isenhower, M. J. Richardson, C. Carello, R. M. Baron, & K. L. Marsh, unpublished data; Richardson et al., 2007a). Our paradigm (Richardson et al., 2007a) involved pairs receiving a continual sequence of light-weight planks; their goal was to move them by grasping them only the ends, as if they were freshly painted in the middle. Some were short enough to be comfortably moved alone, and some were long and thus *required* two people to move. Despite the fact that all of them could have been moved together, participants' actions closely followed the theory of affordances (Gibson, 1977, 1979; see Warren, 1984). Three of the key predictions regarding theorizing about affordances (see Michaels &

Carello, 1981; Richardson et al., 2008) are that information veridically specifies affordances to a perceiver, that perceiver's judgments and actions demonstrate sensitivity to the information, and finally, that affordances are specified by objectively measurable features of the environment taken *with respect to* the organism.

With regards to joint action, therefore, affordance theory predicts that individuals embedded in a social situation will be able to respond to information that specifies their ability for autonomous and joint action, and that their actions will follow accordingly. These predictions were supported by our results (Richardson et al., 2007a). For example, pairs' shifts between solo and joint modes of action were predicted by a relational measure, a body-scaled ratio that assessed the plank length *relative* to the individuals' arm length. Moreover, the shifts were also consistent with dynamical principles. In the body synchrony research, the transition from in- to anti-phase was a discontinuous rather than a gradual shift (Schmidt et al., 1990). This abrupt transition also occurred in the cooperation research. Apart from a few fluctuations in action mode when nearing the critical value of the body-scaled ratio, people were either stably in solo mode or joint action mode. Importantly, the dynamics that occur in these joint perception-action experiments cannot be readily accounted for by traditional judgmental models (Richardson et al., 2007a). Moreover, there was a precise similarity in dynamical processes for shifts within solo action (from one-hand to two-hand grasping) and shifts between solo and joint action. Such similitude provides a strong argument for universal dynamical principles, spontaneous emergence of interpersonal modes of actions when the situational constraints demand them. That is, given the similitude of patterns, we view it as more plausible that these similarities reflect universal dynamical patterns than just chance patterns of joint action that are so precisely parallel to those of solo action.

In contrast to the more naturally paced mode of action of Richardson et al. (2007a), a strategic, trial-and-error analytic mode of deciding how to pick up each piece of wood (as occurs when wood is presented very slowly, Lopresti-Goodman, Richardson, Baron, Carello, & Marsh, 2009) eliminates the dynamical feature of hysteresis. At a normal paced sequence, when individuals started off with large planks of wood that decrease in size, they cooperated longer (i.e., they picked up more smaller pieces of wood cooperatively than when the sequence of wood was from small to large pieces), presumably reflecting a strong cooperation attractor. On the other hand, solo action research (on one- to two-hand grasping) indicates that when the task becomes a more analytic one (e.g., under a slow sequence, with no concurrent task), participant shifts between modes are still predicted by the body-scaled ratio, but without any additional persistence in a given mode due to attractor dynamics (Lopresti-Goodman et al., 2009).

We are additionally interested in whether these two different paradigms, social synchrony and cooperative social action, have a psychological (i.e., judgmental or social cognitive) reality to pairs who are pulled into similar or complementary patterns of movement with each other. Our hypothesis is that these basic movement processes are part and parcel of the emergence of a social unit, and that as such, should have psychological import for those involved in them. Presumably, coordinating and cooperating should be linked to feeling more connected with others. Moreover, individuals who are predisposed to connect with others (or have difficulty doing so) should display stronger (or weaker) pull to coordinated movement and joint action.

3. Social consequences of synchrony and cooperative action

Rather critically, an embodied cooperation task requires that two people come together as ''a unity of action that embraces the participants and the common object'' (Asch, 1952, pp. 173-174). Research on affordances in cooperative lifting, and research on bodily synchrony verifies the utility of an ecological, dynamical perspective for making precise predictions about the emergence of a rudimentary social coordinative structure (e.g., two coupled oscillators in motion) or a goal-directed social unit (as in the cooperation experiments). The next step is demonstrating that these patterns of behavior have demonstrable effects on individuals' feeling of connection with another.

The degree to which experimental inductions make entrainment with another easier rather than difficult should correspond with an individual's rapport, liking, or feeling better able to be a ''team'' with another person. Previous research on raters' subjective judgments of interactants' synchrony is consistent with this view. For instance, Bernieri (1988) found a relationship between dyadic rapport and ratings of interactional synchrony in student–teacher interactions. In our research paradigms, we would also predict that a stronger cooperation attractor (i.e., greater hysteresis when individuals move planks presented in a sequence of descending size) should correlate with participants' subjective reactions to the other individual. (We detail recent research that supports such predictions in a later section.)

A similar prediction is that preexisting dispositional tendencies in sociality dimensions of personality (e.g., extroversion, agreeableness) will affect how strongly a social unity emerges from two individuals' interaction. Schmidt and colleagues (Schmidt, Christianson, Carello, & Baron, 1994) used interpersonal wrist-pendulum coordination to investigate the effects of social competence (Riggio, 1996) upon social coordination stability. Subjects were selected to create homogeneous social competence dyads (High–High or Low–Low pairs) and heterogeneous dyads (High–Low pairs). The heterogeneous (High–Low) pairs demonstrated significantly greater stability and fewer breakdowns in coordination than the homogeneous (High–High and Low–Low) social competence pairings, suggesting that reciprocity (leader-follower) rather than symmetry (leader-leader or follower-follower) of social competence facilitates social coordination. Similarly, questionnaires administered at the end of the plank moving experiment (Richardson et al., 2007a) found that individuals' levels of agreeableness and extroversion (Benet-Martinez & John, 1998) were positively correlated with how much hysteresis (persistence of cooperation in the descending condition) occurred. That is, the degree of cooperation in the plank-moving experiment was positively correlated with the taller of the pair's extroversion in the ascending condition, $r = .51$; the degree of cooperation in the random condition (where planks were received in no ordinal sequence of sizing) was correlated with the agreeableness of the shorter (more constraining) of the individuals, $r = .54$. Dispositional tendencies, in a sense, might set the initial conditions that make pull to the cooperation attractor stronger (or weaker) than a pull to the autonomy attractor (independent action).

Dysfunctions in dynamics of movement should have implications for social disconnection as well. Such disconnection would be expected to arise with preferred tempo of movement that are normatively unusual (very fast or slow walker), or of unusual rigidity (low variability in movement). Individuals who fail to attend to the dynamics of others, either due to lack of ability or lack of motivation would likely feel less psychologically connected when engaging in joint perception and joint action. On the other hand, for those with mild movement limitations, others may provide a ''mooring effect,'' helping those with limitations to be tethered in space and time to the social environment. That is, individuals with somewhat poorer ability to coordinate with the rhythms of the world may be better able to coordinate their actions with the environment if movements of others pulls them into their orbit (see Schmidt et al., 1994). Indeed, much like how arousal from the presence of others serves to facilitate performance on some tasks (Zajonc, 1965), the auditory rhythm movement of the movement of others (and one's own) feet on a long march, or the visual stimulus of the feet of a person in front of oneself continually moving on a long hike up a mountain may provide an energy kick to our own movement, much as a nearby firefly's flash hastens the upcoming flash of another firefly (Strogatz, 1994).

Synchrony may have cognitive benefits as well. Engaging in joint action might employ jointly recruited processes that allow access to others' states (Hutchins, 1995; Semin, 2007; Semin & Cacioppo, 2008). Moreover, being connected socially and environmentally should be felt not only in terms of liking and feeling of entativity (groupness) but also more generalized feelings of harmony and flow—a feeling of perceptual fluency, which may aid memory storage or retrieval processes (Macrae, Duffy, Miles, & Lawrence, 2008; Ravizza, 2003). We would expect that being moored by another may actually *free up* attentional capacity and provide more subsequent cognitive resources (e.g., Richeson & Shelton, 2003).

3.1. Empirical support for synchrony as the basis of emergence of sociality

Four experiments were conducted to test whether, under the most minimal of interaction conditions (no cooperative task), making synchrony relatively easy to achieve would lead to greater feelings of connection than when synchrony was difficult. The first experiment examined ease of intentional synchrony using the pendulum paradigm (Marsh, Richardson, & Schmidt, 2007; Marsh et al., 2006b). The second experiment manipulated the amount of information available in the synchronization of rocking chairs. Participants rocking side by side focused their attention forward, allowing for only peripheral information pickup, or they focused on the arm of the other's chair, providing them focal information about the others' rocking (Marsh et al., 2007). Two other experiments manipulated the frequency differences (detuning) of rocking chairs using matched versus mismatched weighting of chairs. In one of those experiments, a mild rejection induction using ''cyberball''—where other players in an electronic game of catch exclude the participant (Williams, Cheung, & Choi, 2000) preceded the participants' rocking in mismatched chairs. We hypothesized that there would be more feelings of connectedness for participants who participate in conditions where coordination occurs more readily (because of greater availability of information, greater physical ease because of no detuning, or greater motivation due to prior rejection) relative to those in difficult coordination conditions. Here we will review the first two experiments.

In Experiment 1, participants were explicitly asked to entrain their movements in either a difficult or easy coordination task. In the difficult condition, participants were given mismatched pendulums and asked to swing them anti-phase at a rapid tempo. In the easy condition, participants swung pendulums matched in natural frequency and they swung them in-phase at a tempo appropriate for the pendulum length. We predicted that participants who were better able to entrain would have more positive feelings about the other individual, experiencing the interaction as smoother, friendlier, and more harmonious (Bernieri, Gillis, Davis, & Grahe, 1996; Chartrand & Bargh, 1999). As expected, participants had substantially more coordination in the easy condition than did those in the difficult condition. In the easy condition, all pairs' average coherence (an index of how much coordination there was, with 0 meaning no coordination and 1 meaning absolute coordination) values were very high (*M* of .948, *SD* of .05). Even the worst pair, who deviated from intended in-phase by 35°, exhibited a high magnitude of coherence (.97) between the movements of the wrist-pendulums. Fig. 1A and B are illustrative of the patterns that occurred in the difficult condition; where maintaining intended anti-phase was substantially difficult, pairs varied considerably in how much they coordinated. Some pairs (e.g., Fig. 1A) were able to maintain anti-phase coordination, whereas others found it very difficult (e.g., Fig. 1B).

More to the point, dyad-level analyses of interaction attitude surveys revealed that participants in the easy condition had more positive feelings about the interaction than did those in the difficult condition. Easy coordination condition interactions were viewed as significantly friendlier, smoother, and more harmonious and these effects were not reduced when mood effects were partialed out. Furthermore, as Fig. 2A, B illustrate, both the easy and difficult conditions demonstrated that the degree of perceived harmoniousness in the interaction varied with the degree of coordination.

In Experiment 2, attentional focus was manipulated (between-subjects) within a rocking chair paradigm in which participants rocked in chairs side-by-side (see Richardson, et al., 2007b), such that participants in the focal condition had greater information about the movement of the other person's chair than participants in the peripheral condition. Thus, individuals in the focal condition should be more likely to be spontaneously pulled to synchronize, and presumably more sense of connectedness should follow. The cover story of the experiment was that participants were engaged in a memory task and the rocking task was supposedly a distracter. They first would see words appear on the screen in front of them, then they would turn their head in various directions either congruent with the word's appearance (peripheral condition, staring straight ahead) or incongruent (focal condition, staring at an X on the arm of the other's chair). Afterward, each participant was assessed for their perceptions of whether he or she would work well on a team with the other person on (presumed) upcoming tasks. As in Experiment 1, there were significant condition effects on coordination. (There was also substantially lower coherence overall, since coordination was not instructed in this experiment.) Moreover, participants in the focal condition perceived greater smoothness between the pair, and dyad-level analyses indicated that they expressed

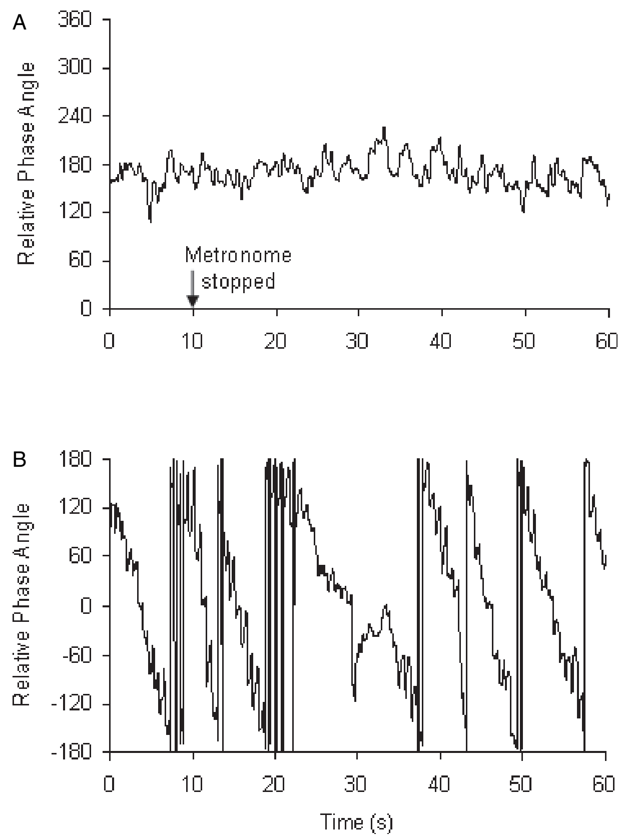

Fig. 1. In the difficult (anti-phase, detuning) condition of Experiment 1, pairs varied considerably in how well they coordinated. The best pair (A) adhered closely to anti-phase (M = 182, SD = 26.4) and had high coherence (.87). The worst pair (B) was unable to maintain anti-phase (visited all possible relative phase angles over time) and had low coherence (.14).

significantly greater sense of ''team-ness'' with the other individual on upcoming tasks than pairs in the peripheral condition. Moreover, coherence was correlated with such perceptions, and coherence partially mediated the condition effects on perceptions.

A final synchrony experiment we report here explores whether children diagnosed with autistic spectrum disorder (ASD) display different patterns of synchrony than typically developing children. ASD is a pervasive developmental disorder that is associated with communication, social imitation and connection deficits (American Psychiatric Association, 1994). Interestingly, the earliest symptoms of this disorder are often movement abnormalities (Grossberg & Seidman, 2006). Some theorists explain ASD as a dysfunction in individual's ''theory of mind'' given the deficits in pretend play, joint attention, and imitation, as well difficulties with language *pragmatics* (Baron-Cohen, 1989; Rogers & Pennington, 1991; Williams, Whiten, & Singh, 2004). However, other recent research provides evidence against such an account (e.g., Carpenter, Pennington, & Rogers, 2001; Sebanz, Knoblich, Stumpf, & Prinz, 2005). An ecological dynamical systems approach suggests that

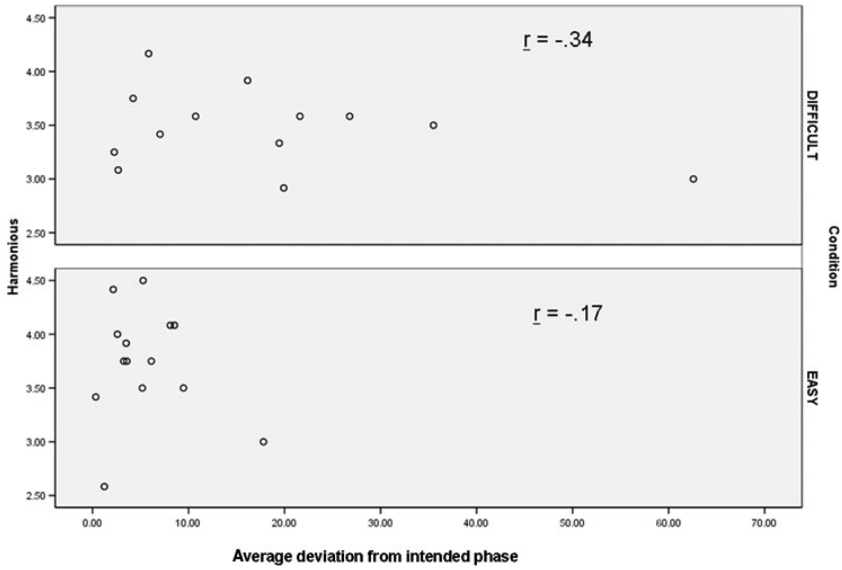

Fig. 2. The relation between average deviation from intended phase (*X* axis) and perceived harmoniousness (*Y* axis) was modest in the difficult condition of Experiment 1, where pairs varied considerably in their synchrony. The correlation was minimal in the easy condition, where there was severe restriction in range for synchrony.

dysfunction in timing of one's own actions and events in the world, in social attention, and in embodiment of one's mind-in-body may be intertwined with ASD (Marsh et al., 2008).

To test this, we examined children's synchrony to a caregiver's rocking while the caregiver read a book to the child. The child was in a child-sized rocker and adult was in a larger chair (weighted to have a natural frequency near that of the child's chair). While reading the book to the child, the adult rocked in tempo with a metronome delivered through an earphone. Although spontaneous synchrony was substantially reduced in children compared to that seen in adults, and some children did not rock during the trials, on a whole, there was significantly less in-phase coordination in children with ASD than in typically developing children. Representative patterns are illustrated by data for two children presented in Fig. 3.

One striking feature of the bodily synchrony studies is that, apart from the child study where parent and child engaged in joint attention while focused on a book, the tasks typically did not involve an interpersonal goal. Yet even in situations where an unintentional interpersonal pull toward synchrony might be at odds with (distract from) the purported experimental goal (e.g., memorizing words), individuals spontaneously coordinated their incidental movements with another individual. The ease of doing so was associated with greater feelings of connectedness—a feeling of readily being a team with the other person. A more obvious expectation of a link between social connection and shared movement would follow from the degree to which engaging in purposive action with another facilitates a connection with them. In questionnaire data collected at the end of the plank-moving embodied cooperation experiments (Richardson et al., 2007a), the strength of the cooperation attractor was found to correlate with participants' felt comfort working with the other

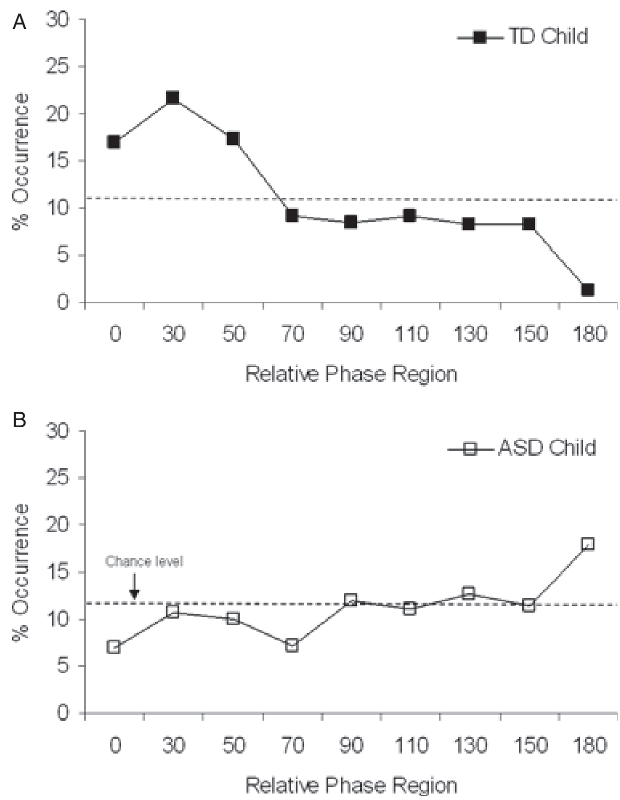

Fig. 3. Frequency of occurrence of in-phase (0°) interpersonal coordination behavior for (A) one prototypical child of typical development (TD) and (B) one prototypic child with ASD.

individual (Marsh et al., 2007*)*. For the taller of individuals in a pair (i.e., those whose height would least constrain their ability to engage in solo action), the degree of hysteresis in the descending-size condition was very strongly correlated (r = .82) with felt comfort. For the shorter of individuals in a pair (i.e., those would be more rapidly constrained to engage in solo action), the degree to which a pair shifted *sooner* to cooperative action in the ascending-size condition was most strongly associated with positive feelings toward the other person (r = .48). In sum, both in the embodied cooperation and coordination of incidental movement studies, we have evidence that that either preexisting affiliative dimensions of an individual, or affiliative consequences (teamness and harmoniousness) are associated with more coordination and cooperation.

4. Conclusions and implications beyond the dyad

There are three primary features of the research discussed that we view as crucial. First is perhaps self-evident from the topic of this special issue, but it is something not common to interpersonal social psychological research, namely that behavioral, embodied methods can be used to investigate sociality. We discussed several paradigms—from the goal-directed cooperative action in the plank-moving paradigm, to the apparently socially trivial, local movement of swinging a pendulum, to the more all-body-encompassing motion involved in rocking a chair. A wide variety of behavioral paradigms demonstrate that we are responsive to movement of another. It is useful to note, however, that this is necessary but not sufficient evidence for its relevance to sociality, since similar bodily synchronization to nonsocial rhythmic stimuli occurs as well (Lopresti-Goodman et al., 2008; Schmidt et al., 2007). Consequently, such entrainment to others could be irrelevant to the question of whether attending to another is a rudiment of forming a social synergy, a social unit of connection with them. However, the recent results reported above demonstrate that being pulled into the orbit of another's body may be a rather fundamental, body-based way for instantiating a socioemotional connection with another.

The second crucial feature of the joint action we have discussed is that it involves *dynamics.* To understand processes of social coordination, we need to turn to the universal logic of stability of natural systems: dynamical processes of self-organization. Such dynamical principles constrain the coordination of limbs of single bodies as well as those of multiple bodies. The research we have reviewed demonstrates the extent to which principles of dynamics that govern the coordination of intrapersonal movements can be used to understand the array of stabilities that arise in interpersonal coordination. Further, we contend that it is via the dynamical laws of energy dissipative systems that emergence of a social unit is even possible. Such a perspective stands in contrast from the top-down, strategic processes involved in deciding to form a coalition with another. In everyday life, spontaneous emergence of temporary form (social ''eddies'') are probably a more frequent part of everyday social life than the intentional actions involved with a cheerleading team doing a planned cheer, clapping and yelling together, a team of rowers rowing together, or a workgroup cooperating to create some work product.

Although in our own work we have focused on dynamical signatures that follow from the HKB equation (in the interpersonal coordination experiments) or from general principles of nonlinear dynamical systems (in the joint action experiments) other means of examining dynamical signatures are available as well. First, the behavior need not be rhythmic and intentional movements of the body (swinging arms, rocking chairs, walking) but can be the rhythms of respiration (Warner, 1996) or stochastic movements such as postural sway (Shockley, Santana, & Fowler, 2003; Shockley et al., 2007). In addition, research has examined the dynamical patterns involved in joint action that is competitive, such as when playing basketball against another person (Newtson, Hairfield, Bloomingdale, & Cutino, 1987), or fencing (Issartel, Marin, Bardainne, Gaillot, & Cadopi, 2005a), or cooperative, as when generating simple dance (Issartel, Marin, & Cadopi, 2005b) or folding a sheet together (Kean, 2000).

The third feature is the embedded nature of our methods and measures. The measurement aims to be truly *at* the level of the relation between the person-person-environment fit rather than inside the head. The focus here is on a social unit at the level of the environment rather than an internal representation of the other's movement that is the focus of a cognitivist, individualist perspective. In particular, our work concerns the emergence of a social unit, two or more individuals acting and perceiving as improbably coherent wholes. Two individuals form a temporarily coordinated unit of social perceiving and action during the course of a brief interpersonal exchange, one brought rapidly into existence with a mere word or gesture, and dissipating as quickly, with individuals nonverbal ''leave-taking'' behaviors. Such units are not mere psychological fictions, but have a clear objectively measurable reality (e.g., degree of coherence in their shared wave forms, amount of time spent in coordinated states). Our conclusion is that understanding social action requires studying social systems as coherent units, with interpersonal and individual behavior, individual dispositional properties (dispositional or group status) and the action capabilities of individual bodies all understood as emergent properties of embodied-embedded joint perception-action systems.

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