Agency and Rhythmic Coordination: Are We Naught but Moving Dots?

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Abstract

There is contention in perceptual-motor research concerning the degree to which observing biological and non-biological movements have equivalent effects on movement production. This issue results from the proposal that action observation and production share neural resources (i.e., mirror neurons) particularly sensitive to actions performed by other 'agents' (i.e., beings with goals/intentions). In support of this claim, several discrete and rhythmic action-observation studies found that action production is only affected when participants believed that observed actions were produced by an agent. Here we present data from two experiments investigating whether similar agency manipulations also affect spontaneous movement synchrony. Collectively, the results suggest that belief in the 'agency' of an observed movement does not affect the emergence and stability of rhythmic movement synchrony. These results question whether the actions of other agents are truly privileged across all scales of coordinated activity, particularly with respect to the lawful dynamics underlying movement synchrony.

Introduction

In our everyday lives, we sustain complex states of coordination. On our way to work we coordinate our actions with our fellow commuters as we jostle for position in rush hour traffic. At work we coordinate our ideas with our colleagues as we develop a new product, policy, or program. Once home for the evening we coordinate with the clock to ensure we are well-rested enough to do it all over again the next day. Certainly, a complete account of coordination should aim at an explanation of these multi-scale, dynamic processes.

Rather than attempting to reduce the full complexity of these phenomena to a sole, dominant process, an alternative approach is to gain an understanding of the nested processes that underlie such coordinated activity. It is in this spirit that researchers have investigated the lawful dynamics of rhythmic movement coordination (e.g., Kelso, 1995; Kugler & Turvey, 1987; Schmidt & Richardson, 2008).

Dynamics of Rhythmic Coordination: Systems of coupled oscillators (e.g., human limbs, pendulums, etc.) generally exhibit similar coordination dynamics regardless of the constitution of the system in question. Early research (Haken et al., 1985; Kelso, 1984; Schöner et al., 1986) demonstrated that rhythmic movements of oscillatory limbs belonging to the same individual (e.g., fingers, arms, legs) exhibited two stable modes of entrainment, namely inphase and antiphase coordination. These two coordination modes are captured by the collective variable *relative phase* (Φ), with inphase and antiphase coordination corresponding to $\Phi = 0^{\circ}$ and $\Phi = 180^{\circ}$, respectively. These two modes of coordination are intrinsically stable (are produced without practice), although antiphase coordination is less stable than inphase coordination. This difference in the relative stability of inphase and antiphase coordination is reflected by the fact that the variability of antiphase coordination is greater than the variability of inphase coordination and that individual's transition from antiphase to the inphase coordination under certain movement conditions (i.e., high movement frequencies).

More recent research has demonstrated the same coordination dynamics constrain oscillatory movements produced by separate individuals (e.g., Richardson et al., 2007; Schmidt et al., 1990; Schmidt & O'Brien, 1997). Provided a visual coupling, the coordination that occurs between the movements of two individuals is constrained to inphase and antiphase patterns of coordination (without practice), with antiphase being less stable than inphase coordination (e.g., Richardson, et al., 2007; Schmidt et al., 1990). Research has further demonstrated that similar coordination dynamics can occur spontaneously (i.e., unintentionally), with the rhythmic movements of two visually coupled participants become coordinated even when they are not instructed to do so (e.g., Oullier et al., 2008; Richardson et al., 2005; Schmidt & O'Brien, 1997). Whereas intentional movement synchrony produces *phase-locking*, indicated by absolute concentration of relative phase at the instructed mode (i.e., either at 0° or 180°), spontaneous coordination results in intermittent or *relative entrainment*, which is characterized by a tendency for relative phase differences to cluster around 0° and 180°. Despite this difference, however, states of relative synchrony display similar coordination dynamics (e.g., individual's exhibit less antiphase entrainment).

Interestingly, the same coordination dynamics are evident in systems comprised of an individual participant and a non-biological environmental stimulus (e.g., Lopresti-Gooman et al., 2007; Schmidt et al., 2007). As with inter-personal movement synchrony, the entrainment between the movements of a participant and an environmental rhythmic stimulus can occur both intentionally and unintentionally. Such entrainment exhibits the same two modes of coordination with the same relative stabilities. Thus, the phenomenon of visual rhythmic movement synchrony suggests that these processes are constrained by the same lawful coupled oscillator dynamic, regardless of the nature of the components comprising the system.

Agency Effects: Although the above results indicate that the same coordination dynamics result for all systems of coupled oscillators, there is some question as to the degree to which coordination with an environmental stimulus approximates the social coordination that exists between two humans. This question is justified given the discovery of mirror neurons in Macaque monkeys, which do not differentiate between produced and observed actions, but only when the observed actions are produced by another agent (see Rizzolatti et al., 2004 for a review). The human 'mirror neuron system' appears to have a similar preference, in that the system does not appear to have an equivalent response to agent and non-agent based action (e.g., Buccino et al., 2001; Fadiga et al., 1995).

Within the behavioral literature, there is also evidence to suggest that the observation of agent and non-agent based action can have a differential effect on movement production (e.g., Castiello et al., 2002; Brass et al., 2001). Press et al. (2005) had participants produce either hand-opening or hand-closing movements in response to stimuli that depicted a compatible or incompatible action. In the agent condition the stimuli were still images of a real human hand, whereas in the non-agent condition the stimuli were images of a robotic pincher. The results revealed that participants were faster to respond and made fewer errors when the observed actions were compatible than when they were incompatible and that this action facilitation/interference effect was greatly reduced in the non-agent condition.

Similarly, research by Kilner et al., (2003) and Stanley et al., (2007) has demonstrated how a participants' belief in the agency of an observed movement can also influence the production of a rhythmic limb movement. More specifically, these studies have demonstrated that individuals exhibit greater rhythmic movement variability when observing a spatially incongruent movement compared to a spatially congruent movement, but that this effect depends on the perceived agency of observed movements. That is, observing movements produced by an agent, or believed to be produced by an agent, resulted in greater rhythmic movement variability than observing movements produced by a non-agent (i.e., computer generated movement or the movements of a robot).

Although these studies have supported the existence of 'agency effects' in both discrete and rhythmic *movements*, no research has been conducted to investigate such effects in rhythmic movement *synchrony*. That is, no studies have investigated whether a participants' belief in the agency of an observed movement influences the stability or emergence of rhythmic entrainment. Here we present data from two experiments specifically designed to examine this question.

Experiment 1

Participants were required to produce rhythmic movements of the forearm while observing the rhythmic movements of a dot stimulus on a large projection screen. Participants were informed that the movements they were observing were either computer-generated movements, or pre-recorded human movements, or the real-time movements of a confederate positioned on the opposite side of the screen. In all conditions the movements of the stimulus were in fact computer-generated.

Method

Participants: Twenty-five undergraduate students from the University of Cincinnati participated for partial course credit. All participants had normal or corrected-to-normal vision, had no history of movement disorders, and were over 18 years of age.

Apparatus: A 1.25 x 1.7 m rear-projection screen and an Epson Powerlite 53c projector (Epson America, Long Beach, CA) displayed a red dot with a 5 cm diameter oscillating horizontally. A FASTRACK magnetic motion-tracking system (Polhemus Ltd., VT) recorded the participants' horizontal arm movements at a sample-rate of 60 Hz.

Design and Procedure: Following consent, participants were instructed that the purpose of the experiment was to investigate the effects of irrelevant movement on symbolic processing. This cover story was employed to keep participants from discerning the true purpose of the experiment (i.e., rhythmic coordination). They were told their task was to read single letters from the stimulus-display and repeat them aloud as quickly as possible. They were instructed that on each trial they were to produce rhythmic movements of their right forearm as a distraction to the symbolic processing task. They were also instructed that on some trials the letters would appear on a stationary stimulus and on other trials the letters would appear on a moving stimulus as an additional distraction. Finally, embedded within task instructions, participants were told that the movements of the stimulus displaying the letters were either computer-generated (n = 9), pre-recorded human movement (n = 9), or the real-time movements of confederate positioned on the opposite side of the projection screen (n = 7).

On each trial, participants began to produce rhythmic movements and then read letters from the stimulus-display. The letters appeared on top of the dot stimulus every 2 s with a random offset between 0 and 0.99ms. Participants completed six trials in which the stimulus displaying the letters was stationary (i.e., control condition). On these trials, there was a hidden oscillating stimulus which allowed for an assessment of chance-level coordination. Participants also completed six trials in which the stimulus displaying the letters oscillated horizontally across the screen (i.e., experimental condition). On these trials, displaying the letters on the stimulus ensured that participants tracked its movements. Each trial lasted 60 seconds. Upon completion of the experiment participants underwent a funnel debriefing procedure to assess whether participants had discerned the true nature of the experiment.

Data Analysis: The first 5 s of each trial were discarded to eliminate any transient behavior. The remaining 55 s of each trial were then normalized around 0, and low-pass filtered with a 10 Hz Butterworth filter. Distribution of relative phase (DRP) was calculated to evaluate the coordination between participant and stimulus movements. DRP evaluates the concentration of relative phase angles between two movement time-series across nine 20^{o} regions of relative phase (0-20 °, 21-40 °, 41-60 °, 61-80 °, 81-100 °, 101-120 °, 121-140 °, 141-160 °, 161-180 °). Entrainment is indicated by a high concentration of relative phase angles near 0 ° (inphase) and 180 ° (antiphase), while an even distribution indicates no phase-entrainment.

Results and Discussion

A 2 (condition) x 9 (phase region) x 3 (agency) mixed ANOVA on DRP revealed a significant effect of phase region [F (8, 15) = 5.59, p < .05] with a concentration of phase angles around the 0° (inphase) and 180° (antiphase) relative phase regions. There was a significant interaction between condition and phase region [F (8, 15) = 5.11, p < .05] with concentration in the 0° and 180° regions evident only in the experimental trials. There were no significant effects of agency (see Figure 1).

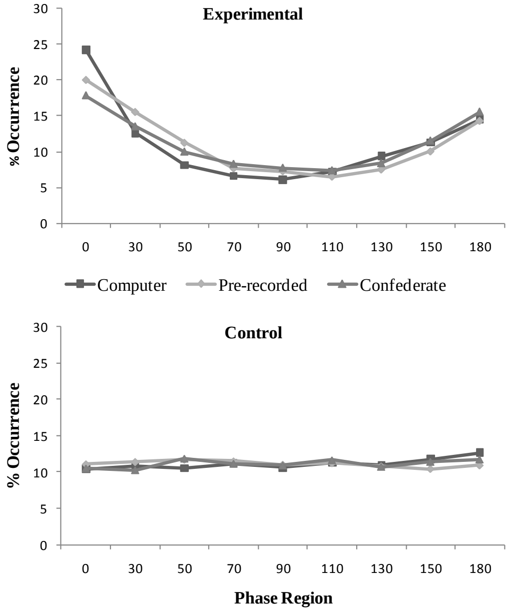

Figure 1. Distribution of relative phase as a function of agency and condition (Experiment 1).

The results of this experiment suggested that there were no effects of agency on the emergence or stability of rhythmic coordination. The DRP profile from the control condition revealed the pattern expected for chance-level coordination, with similar occurrence of relative phase angles in all regions. The DRP profile from experimental trials revealed the pattern expected for spontaneous, intermittent coordination between a participant and rhythmic stimulus movement (Schmidt et al., 2007; Lopresti-Goodman et al., 2009). That is, there was a concentration of relative phase angles around the 0° (inphase) and 180° (antiphase) regions, with slightly more occurrence around 0°. There were, however, no differences in the DRP profiles as a function of agency, indicating that the participants' belief as to the source of the observed stimulus movements did not affect the pattern of coordination.

Although these data suggest that agency does not influence the stability of rhythmic movement coordination, there was another possibility for the lack of agency effects in this experiment. As demonstrated in prior research (Schmidt et al., 2007), procedures that require participants to track the stimulus movements result in a greater degree of entrainment compared to conditions in which participants do not track stimulus movements. Thus, it was possible that employing the visual tracking methodology in Experiment 1 increased the level of observed coordination generally and that the strength of the visual coupling may have eliminated the potential for more subtle effects to be observed.

Experiment 2

To determine whether the lack of an agency effect in Experiment 1 was due to the strong visual coupling, we conducted a second experiment in which the participants did not track the movements of the stimulus, resulting in weaker visual coupling (Schmidt et al., 2007). If a participant's belief in the agency of stimulus movements has only subtle effects on coordination then such effects might be evident when the strength of the visual coupling was reduced.

Method

Participants: Twenty-seven undergraduate students from the University of Cincinnati participated for partial course credit. All participants were over 18 years of age, had normal or corrected-to-normal vision, and had no movement disorders.

Apparatus & Procedure: The experimental equipment was exactly the same as in Experiment 1. The design and procedure was also the same as in Experiment 1, with the sole exception that during experimental trials letters appeared on a centered, stationary stimulus, while the moving stimulus appeared on a horizontal trajectory directly behind the stationary stimulus. Thus, participants observed but did not track the moving stimulus.

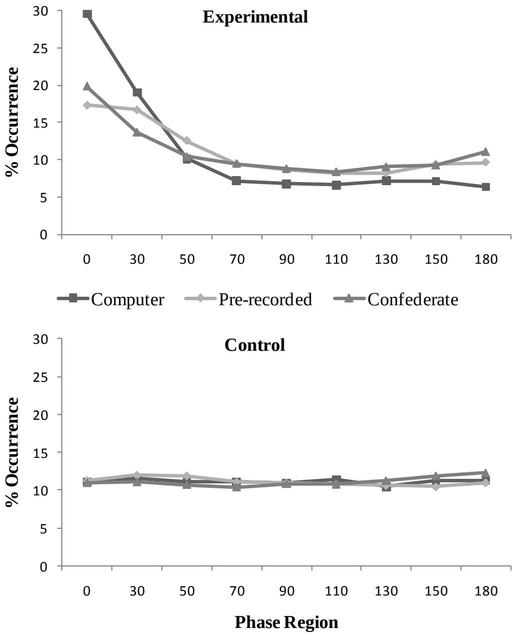

Figure 2. Distribution of relative phase as a function of agency and condition (Experiment 2).

Results

A 2 (condition) x 9 (phase region) x 3 (agency) mixed ANOVA on DRP revealed a significant effect of phase region [F (8, 17) = 4.33, p < .01] with a concentration of phase angles in the 0° (inphase) region. There was a significant interaction between condition and phase region [F (8, 17) = 2.66, p < .05] with the concentration in the 0° region evident only in the experimental trials. There were no significant effects of agency evident in the DRP (see Figure 2).

Discussion

As in Experiment 1, the results of the second experiment also suggest that agency has no effect on the emergence or stability of rhythmic coordination. As before, the DRP profile for the control and the experimental condition revealed the pattern expected for chance-level and spontaneous entrainment, respectively (Lopresti-Goodman et al., 2009; Schmidt et al., 2007). In contrast to the results of Experiment 1, there was only a concentration of phase angles around the 0° relative phase region (i.e., not in the 180° region). This is likely a result of the decrease in the general level of coordination associated with the switch from a tracking to a non-tracking procedure. The antiphase mode, being the less stable of the two modes of coordination, is the first of the two to disappear as the general level of coordination is decreased (Richardson et al., 2005; 2007).

General Discussion

Collectively, the results of the two experiments presented above suggest that a participant's belief in the agency of an observed movement has no effect on the emergence or stability of rhythmic movement synchrony. Rhythmic entrainment consistently emerged between the participants' movements and the stimulus' movements, and the stability of entrainment, as revealed by the DRP profiles, was as expected. The participants' beliefs concerning the agency of the stimulus movements, however, had no reliable effect on entrainment. Thus, these data might be argued to support a general equivalence in rhythmic entrainment between systems comprised of agents and non-agents. There are, however, several possible methodological and statistical alternatives that must be resolved before such a conclusion is merited.

First, it is possible that the failure to observe an agency effect is in fact a lack of statistical power resulting from a small sample size. The sample size employed in the present experiments was standard with respect to both number of participants and number of trials (Kilner et al., 2007; Stanley et al., 2007). Similarly, it is possible that the employed statistical test was insufficient to capture any subtle agency effects in the data. In addition to the statistical analyses presented here, a range of other methods, including comparing quadratic fits to DRP profiles by individual participant and a meta-analysis across both experiments, have all failed to reveal an effect of agency.

Second, it is possible that the failure to observe agency effects is a result of how agency was manipulated in the present experiments. The primary concern would be that participants might not have believed that the observed movements reflected real human movement. The funnel debriefing procedure revealed that not a single participant suspected that the stimulus movements were not as instructed. Another alternative is that these results might be explained by the nature of the stimulus movements. The present experiments utilized only computer-generated, sinusoidal movements. Kilner et al. (2007) have found evidence to suggest that agency effects might only arise when the movements in the human condition reflect real human movement. Additionally, it is possible that, in manipulating agency as a between-subjects variable, the present obscured effects at the level of the individual participant. We are currently conducting experiments to investigate these and similar issues.

It is equally likely, however, that these data reflect the equivalence of the coordination that occurs between two individuals and between an individual and a non-biological environmental stimulus. This latter conclusion supports the contention that all systems of coupled oscillators are governed by the same lawful processes and, whether coupled biomechanically or via visual information, will become entrained to one another given sufficient coupling strength. This claim should neither be taken to invalidate the results of prior investigations that revealed 'agency effects' at the neurological and behavioral levels, nor to suggest that 'agency' is not a concept worth further investigation. Instead this work is intended to further establish the theoretical boundaries for 'agency' as an explanatory concept. While our beliefs and knowledge about the goals and intentions of other agents are certainly an indispensible component to an account of coordinated behavior in its full complexity, it is a worthwhile consideration that such refined aspects of human behavior have their foundations in the deep, underlying support of natural law.

References

Brass, M., Bekkering, H., & Prinz, W. (2001). Movement observation affects movement execution in a simple response task. *Acta Psychologia, 106,* 3-22.

Buccino, G., Binkofski, F., Fink, G. R., Fadiga, L., Fogassi, L., Gallese, V., Seitz, R. J., Zilles, K., Rizzolatti, G., & Freund, H. J. (2001). Action observation activates premotor and parietal areas in a somatotopic manner: an fMRI study. *European Journal of Neuroscience, 13,* 400-404.

Castiello, U., Lusher, D., Mari, M., Edwars, M., & Humphreys, G. W. Observing a human and a robotic hand grasping an object: Differential motor priming effets, in: W. Prinz, B. Hommel (Eds.), Common Mechanism in Perception and Action, Attention and Performance XIX, Oxford University Press, New York, 2002.

Fadiga, L., Fogassi, L., Pavesi, G., & Rizzolatti, G. (1995). Motor facilitation during action observation: A magnetic stimulation study. Journal of Neurophysiology, 73, 2608-2611.

Haken, H., Kelso, J. A. S., Bunz, H. (1985). A theoretical model of phase transitions in human hand movements. *Biological Cybernetics*, *51*, 347-356.

Kelso, J. A. S. (1984). Phase transitions and critical behavior in human bimanual coordination. *American Journal of Physiology: Regulatory, Integrative and Comparative*, *246*, R1000-R1004.

Kelso, J. A. S. (1995). Dynamic patterns. Cambridge, MA: MIT Press.

Kilner, J. M., Hamilton, A. F. C., & Blakemore, S. J. (2007). Interference effect of observed human movement on action is due to velocity profile of biological motion. *Social Neuroscience*, *2*, 158-166.

Kilner, J. M., Paulignan, Y., & Blakemore, S. J. (2003). An interference effect of observed biological movement on action. Current Biology, 13, 522-525.

Kugler, P. N. & Turvey, M. T. (1987) Information, natural law and the self-assembly of rhythmic movement. Erlbaum, Hillsdale.

Lopresti-Goodman, S. M., Richardson, M. J., Silva, P. L., & Schmidt, R. C. (2007). Period basin of entrainment for unintentional visual coordination. *Journal of Motor Behavior*, *40,* 3–10.

Oullier, O., de Guzman, G. C., Jantzen, K. J., Lagrade, J., & Kelso, J. A. S., (2008). Social coordination dynamics: Measuring human bonding. *Social Neuroscience*, *3*, 178-192.

Press, C., Bird, G., Flach, R., & Heyes, C. (2005). Robotic movement elicits automatic imitation. *Cognitive Brain Research*, *25*, 632-640.

Richardson, M. J., Marsh, K. L., Isenhower, R., Goodman, J., & Schmidt, R. C. (2007). Rocking together: Dynamics of intentional and unintentional interpersonal coordination. *Human Movement Science*, *26*, 867-891.

Richardson, M. J., Marsh, K. L., & Schmidt, R. C. (2005). Effects of visual and verbal interaction on unintentional interpersonal coordination. *Journal of Experimental Psychology: Human Perception and Performance*, *31*, 62-79.

Rizzolatti, G. & Craighero, L. (2004). The mirror neuron system. *Annual Review of Neuroscience*, *27*, 169-192.

Schmidt, R. C., Carello, C., & Turvey, M. T. (1990). Phase transitions and critical fluctuations in the visual coordination of rhythmic movements between people. *Journal of Experimental Psychology: Human Perception and Performance*, *16*, 227-247.

Schmidt, R. C., & O'Brien, B. (1997). Evaluating the dynamics of unintended interpersonal coordination. *Ecological Psychology*, *9,* 189-206.

Schmidt, R. C., & Richardson, M. J. (2008). Dynamics of Interpersonal Coordination. In A. Fuchs & V. Jirsa (Eds.). Coordination: Neural, Behavioral and Social Dynamics. (pp. 281-308). Heidelberg: Springer-Verlag.

Schmidt, R. C., Richardson, M. J., Arsenault, C. A., & Galantucci, B. (2007). Visual tracking and entrainment to an environmental rhythm. *Journal of Experimental Psychology: Human Perception and Performance*, *33*, 860-870.

Schöner, G., Haken, H., & Kelso, J. A. S. (1986). A stochastic theory of phase transitions in human hand movement. *Biological Cybernetics*, *53*, 247-257.

Stanley, J., Gowen, E., & Miall, R. C. (2007). Effects of agency on movement interference during observation of a moving dot stimulus. *Journal of Experimental Psychology: Human, Perception, and Performance*, *33*, 915-926.

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