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Research paper

Does interpersonal movement synchronization differ from synchronization with a moving object?

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HIGHLIGHTS

- We examined the effect of agency on synchronization with a person or an object.
- The task involved intentional, unidirectional coupling with the reference movements.
- The strength of coupling to the reference movements was comparable in all conditions.
- Participants' movements were less phase advanced when synchronizing with an agent.
- Synchronizing with an agent affected the form of the coupling but not its strength.

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ABSTRACT

We examined whether movement synchronization is different during coordination with another person than during coordination with a moving object. In addition, the influence of belief in the other person's agency was assessed. Participants synchronized their lower-arm movements with a computer-controlled rhythmic reference movement. The reference movements were pre-recorded, biological movements and were identical in all conditions. They were presented either by means of a confederate's arm in a motor-driven manipulandum or by means of movements of the manipulandum alone. To assess the influence of the belief in the confederate's agency, participants either were or were not informed that the confederate's movements were motor driven. The strength of coupling between the participant's movements and the reference movements was assessed in terms of the standard deviation of relative phase and the time needed to re-establish the coordination pattern after an unexpected perturbation of the reference signal. Mean relative phase indicated whether the participant was leading or lagging the reference movements. Coupling strength was not affected by the presence of another person in the coordination task, nor by the belief in this person's agency. However, participants had a stronger tendency to lead while synchronizing with the manipulandum, indicating that they responded differently to the observed kinematics of this moving object than to the kinematics of the confederate's arm movements, at least when the confederate's agency was assumed. Hence, although neither the involvement of another person nor the participant's belief in this person's agency affected coupling *strength*, the *form* of the coupling seemed to be influenced by the former factor, suggesting a different attunement to the reference movements during a joint-action situation. Future research is required to determine whether these interpretations extend to unintentional and bidirectional coordination, in which agency is not only assumed but actually effectuated.

1. Introduction

Every day we coordinate our movements with other persons, for instance when shaking hands, dancing, walking together, and even when talking [6]. Such interpersonal coordination, or joint action, has received considerable attention in recent years [27,29,30]. From a cognitive psychological perspective, the fundamental tendency to attune our actions to those of another person has been related to common coding of perception and action and to the mirror neuron system [2,30]. The mirror neuron system is particularly attuned to goal-directed actions of other agents and was found, in monkeys, to respond differently to actions performed with a human effector (hand) than with a tool (pliers) [23]. This raises the interesting possibility that coordinating our movements with those of another

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person may involve essential differences from coordination with a moving inanimate object or stimulus.

The coordination dynamics perspective [27], however, has demonstrated that interpersonal coordination shows striking similarities with not only bimanual coordination [25,26,28], but also the coordination with an external stimulus [17,32]. In all these situations, anti-phase and inphase rhythmic movements are stable patterns of coordination, with anti-phase being less stable than inphase coordination [24,28], and spontaneous transitions from anti-phase to inphase coordination resulting from increasing movement frequency [7,25,32]. At first blush, these similarities between the dynamics observed for coordination with another person and with a non-biological signal may suggest that the origin of a perceived rhythmic movement pattern is immaterial to the way in which it influences the perceiver's movements.

However, there are several indications that social aspects of interpersonal coordination affect the mutual influences between the coordinated rhythms. For example, social characteristics of the persons involved tend to affect the resulting coordination dynamics [11,26]. Moreover, the strength of coordination with a confederate appeared to be affected by whether or not he/she belonged to the same group as the participants [15] and by antipathy against the confederate [14]. Such influences of social context onto interpersonal coordination suggest that the coupling (or: interaction) effects that govern synchronization with another person are not identical to those underlying synchronization with an inanimate external stimulus. Indeed, in children spontaneous synchronization was more apparent when drumming along with an adult than when drumming along with a mechanical 'hand' playing a drum or with a pre-recorded beat [10]. Likewise, incongruent perceived movements of another person have stronger interference and priming effects than those of a robot [9,21].

Such differences between the coordination with an agent (a being with goals/intentions and associated goal-directed actions; e.g., another person) and a non-agent (e.g., object) may be associated with neuroimaging results indicating that our brain treats perceived biological movement differently than perceived non-biological movement [2]. In this context, the differences in the kinematics of biological and non-biological movements seem to be relevant [2,8]. In addition, the differences in coordination with an agent or a non-agent may be associated with the mere fact that the participant knows or believes that he/she is coordinating with an agent or not. Recently, Coey et al. [3] addressed the potential influence of participants' belief in agency associated with the movements of a projected visual dot by suggesting that these movements were either computer generated (which was actually the case in all conditions), pre-recorded human movements, or on-line generated by another person. However,the absence of a visibly present person may have hampered the manipulation of the belief in agency, which may have been the reason why no effect of agency was obtained.

The present study was designed to examine whether rhythmic synchronization is affected by the presence of another agent. As explained in the next paragraph, we created three conditions that suggested to entail different degrees of agency. To avoid confounding effects of movement kinematics, the same pre-recorded biological movement signals were used in all conditions. To assess the effects on synchronization, we focused on the strength of the coupling influences. Because the stability features of the resulting coordination patterns result directly from the coupling (interaction) between the oscillating components [18], coupling strength (i.e., the degree to which the oscillating components are influenced by each other) is a key characteristic in coordinative settings. We used the perturbation paradigm developed by De Poel et al. [4], which was recently successfully applied to interpersonal coordination by Peper et al. [19]. Within this paradigm, the shared coordination pattern is briefly interrupted by means of a mechanical perturbation. Thanks to the mutual interactions between the rhythmic movements within a dyad, both persons are expected to adapt their movement phasing to re-stabilize the shared coordination pattern by speeding up or slowing down their individual movements [12,19]. The individual contributions of the participants to the re-stabilization of the coordination pattern provide a measure of coupling strength.

To achieve a reliable comparison, we used a set-up with a computer-controlled manipulandum. Participants were instructed to synchronize their lower-arm movements with those of a confederate's lower arm that was positioned in that manipulandum, or with the movements of the manipulandum itself. In all conditions the movements of the manipulandum were identical and based on pre-recorded human (i.e., biological) arm movements. In condition Person-A (Person-Agent), participants had to synchronize with a confederate while they were unaware of the fact that the reference movements of the confederate were computer controlled. Pilot sessions revealed that participants did not notice that the confederate's arm was moved passively. In condition Person-N (Person-Non-agent), participants received the same instructions, but they were informed that the arm of the confederate was being moved passively. In condition Object, the movements were to be synchronized to those of the manipulandum, without the confederate being involved.

Comparison of conditions Person-N and Object allowed for examining whether sharing the coordination task with another person (as opposed to an object) affected the way in which the participant was influenced by the other movements. By comparing Person-N to Person-A we examined whether this influence was affected by the participant's belief that the other person was actively involved in the joint synchronization task, i.e., the belief in the confederate's agency. We hypothesized that coupling strength would be higher during synchronizing with a partner compared to an object, in particular when the participant was not aware that the confederate did not actively contribute to the joint performance (i.e., when the partner's agency was assumed; condition Person-A).

2. Methods

2.1. Participants

Twelve right-handed females (aged 18–31 years; mean laterality quotient = 86, range 41–100; [16]) participated and gave their informed consent in advance. The experiment was approved by the local ethics committee.

2.2. Experimental set-up

Participants sat on a modified chair with their right elbow nearly 90° flexed. Their right lower arm was fixated in a manipulandum that only allowed rotation in the horizontal plane. The manipulandum registered the angular excursions of the lower-arm movements (potentiometer: FCP40A, tolerance ±0.1%, Sakae Tsushin Kogyo Co., Ltd., Nakahara-ku, Kawasaki-city, Japan; sampling rate: 200 Hz). Opposite to the participants, a second manipulandum was positioned. The movements of this manipulandum were controlled by means of a servo-motor (Parvex RS440GR1031, SSD Parvex SAS, Dijon Cedex, France) and a precision gearbox (alpha TP010S-MF1-7-0C0, backlash ±0.02°, Wittenstein, Inc., Bartlett, IL, USA). Motor files were transmitted to the servo-motor to control the movement of the manipulandum. These motor files were time series of pre-recorded rhythmic human movement of the lower-arm with or without perturbation, as obtained during interpersonal coordination. Hence, the movements of the manipulandum contained natural variation and showed a nat-