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Social constraints from an observer's perspective: Coordinated actions make an agent's position more predictable

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ABSTRACT

Action prediction, a crucial ability to support social activities, is sensitive to the individual goals of expected actions. This article reports a novel finding that the predictions of observed actions for a temporarily invisible agent are influenced, and even enhanced, when this agent has a joint/collective goal to implement coordinated actions with others (i.e., with coordination information). Specifically, we manipulated the coordination information by presenting two chasers and one common target to perform coordinated or individual chases, and subjects were required to predict the expected action (i.e., position) for one chaser after it became momentarily invisible. To control for possible low-level physical properties, we also established some intense paired controls for each type of chase, such as backward replay (Experiment 1), making the chasing target invisible (Experiment 2) and a direct manipulation of the goal-directedness of one chaser's movements to disrupt coordination information (Experiment 3). The results show that the prediction error for invisible chasers depends on whether the second chaser is coordinated with the first, and this effect vanishes when the chasers behaves with exactly the same motions, but without coordination information between them; furthermore, this influence results in enhancing the performance of action prediction. These findings extend the influential factors of action prediction to the level of observed coordination information, implying that the functional characteristic of mutual constraints of coordinated actions can be utilized by vision.

1. Introduction

The ability to predict and anticipate the actions of others is crucial for planning appropriate behaviors before engaging or intervening in observed actions (Csibra & Gergely, 2007; Hauser & Wood, 2010). Evidently, people are able to generate predictions even with limited information about agents' actions (Csibra, Bíró, Koós, & Gergely, 2003; Saunier et al., 2013). This sophisticated ability is thought to be sensitive to an individual's goals (or just the associative contingency between actions and outcomes) (Gergely & Csibra, 2003; Verschoor, Spapé, Biro, & Hommel, 2013). However, people's actions are not always framed as pursuing their own individual goals. Instead, they are often embedded in coordinated interactions to achieve a collective/shared goal, which are referred to coordinated or joint actions (Knoblich & Sebanz, 2008; Sebanz, Bekkering, & Knoblich, 2006). Less is known about whether this interpersonal coordination information, beyond individual goals, could influence action prediction.

Recently, some researchers have started to explore how the information conveyed by coordinated actions affects action processing/understanding. Observing coordinated interactions has been consistently found to have a tangible benefit for extracting information from actions or at least in detecting the actors. For instance, Neri et al. (2006) found the visual discrimination of a human agent is influenced by the second agent when their actions involving physical contact could be interpreted as meaningful coordination (i.e., fighting or dancing); Manera et al. (2011) confirmed this conclusion, showing that communicative gestures, even without contact, can increase the likelihood of perceiving a second agent. The above efforts notwithstanding, no direct evidence has illustrated the role of observed coordinated interaction in action prediction.

Interpersonal coordination is not only a mere summation of individual actions, but most importantly, it is also more than the individual elements, as its behaviors are interdependent and may sometimes be mutually complementary (Sebanz et al., 2006).

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Moreover, coordinated actions are thought to be constrained by each other within a coordinative structure (Shockley, Richardson, & Dale, 2009). For instance, Shockley, Santana, and Fowler (2003) found that mutual interpersonal postural constraints (i.e., sharing more locations in phase space) are involved during conversation in a coordinated manner. Although it is still under debate whether the emergence of this social constraint is supported by acting together with shared representation across persons or is due to spontaneous organization (Sebanz et al., 2006; Shockley et al., 2009), in any case, such a structured constraint ensures that the adjustment of one's actions could result in predictively aligned changes of other people' actions when the people interact in a coordinated fashion. Therefore, from the observer's perspective, the actions of one agent could serve as efficient predictors for the actions of other agents in a coordinated interaction. Thus, when observing a coordinated interaction, even when an agent temporarily disappears, the vision could use the characteristic of mutual constraints in coordinated actions to reduce possible hypothesis spaces when inferring or predicting the actions of the invisible agent. In this case, an observer should generate much better predictions for the temporarily invisible actions that are involved in interpersonal coordination, in comparison with those that are not involved in interpersonal coordination. Namely, the observed coordination information should influence, and even enhance, the predictive accuracy for the expected actions.

To test our hypothesis, the manipulation of the coordination information used two types of dynamic chase scenes, in which two agents acted as chasers running in a coordinated or individual manner, toward a common prey.[1] The different chase scenes were modelled after displays used by Heider and Simmel (1944) that presented geometric figures only in a chasing motion. One of the advantages of this method is that motion is the only action information that contributes to the understanding of semantic social meaning; thus, if we are interested in social information (e.g., chasing relation, coordination information), only the physical features of motion need to be controlled. Previous research has extensively used this type of chasing motion, but with only one chaser, to explore the perception of animacy, intention, and interaction (Dittrich & Lea, 1994; Gao, Newman, & Scholl, 2009). All of these studies documented that the motion sequences should not simply be treated as physical movement; they should be thought of meaningful actions with goals, which influences our other processes accordingly, such as visual searches and interactive behaviors (Gao, McCarthy, & Scholl, 2010; Meyerhoff, Schwan, & Huff, 2014). Usually, the chasing motion with one chaser and one target was generated with specific steering rules by referring to AI algorithms. With two chasers and one target of multi-agent chasing, the principles of movement have not been determined (Rawal, Rajagopalan, & Miikkulainen, 2010). Thus, it is better to rely on man-made trajectories than to use AI algorithms to describe multi-agent chasing. Indeed, our previous research successfully used the recorded motion of real people as they controlled their own avatars (chasers) in a coordinated or individual chase toward the same target (Yin et al., 2013). As well, the current research has adopted methods of using recordings of human motion to display coordinated and individual chases.

To examine the role of coordination information on action prediction, the recorded motions from both coordinated and individual chases were shown in a forward sequence to subjects who were required to predict the expected position (i.e., action) for one chaser after it became momentarily invisible. To further isolate the effect of socially coordinated information from possible low-level physical properties, we also established some intense paired controls for each type of chase, such as backward replay (Experiment 1), making the chasing target invisible (Experiment 2), and a direct manipulation of the goal-directedness of one chaser's movements to disrupt coordination information (Experiment 3). If coordination information enhanced the prediction of actions, we should observe fewer prediction errors in coordinated chases compared with the controls, but not in individual chases.

2. Experiment 1a

Both the coordinated and individual chases were presented by forward replaying of recorded trajectories and were compared with their own controls, which consisted of backward replays of the same trajectories. In such settings, the physical features were the same in the two types of replay sequences, whereas in the backward replay, the chasers' intended actions became inverted and ambiguous, disturbing the processing of social meaning behind them (though it never disappeared completely). Accordingly, the distinction between the forward and backward trajectories was comprehensible to an observer who understood the interpersonal coordination between chasers. Therefore, the differences in action predictions between the forward- and backward-replayed stimuli should be attributed to the experienced social interaction between the two chasers.

2.1. Method

2.1.1. Participants

Fourteen naïve Zhejiang University students (7 males and 7 females; mean age: 21 years; range: 18–26 years) participated in the experiment for a financial reward. All of them had normal or corrected-to-normal vision. All participants provided written and informed consent before participating in the experiments and the procedures were approved by the Research Ethics Board of Zhejiang University and the granting agency.

2.1.2. Stimulus design

The movement trajectories were recorded according to the following steps. Three participants as a group were asked to finish a chasing game and sit without head restraint approximately 60 cm from a monitor (the measurements were computed based on this viewing distance; 28 pixels = 1° or 1 cm). In total, five groups were included (6 males and 9 females; age range: 18–26 years). Each of them in a group controlled an agent with a mouse on the screen: one played the role of prey by controlling a red square ($1° \times 1°$), and the other two played the role of chasers by controlling green and blue disks of 1° diameter. The two chasers were required to chase the common prey, either in a coordinated manner (i.e., cooperatively) or individually (i.e., capturing the target on his or her own), and the prey tried to avoid being caught. If any chaser reached the prey, the trial ended. To prevent the prey from being caught at the beginning, the initial distances between each pair of agents were greater than 5°. Participants could move the agents less than 0.5°/frame and the controlled agents could not pass each other according to the algorithm that each agent cannot occupy the same space of the remaining agents on the screen; they controlled only their own agents within a common zone bounded by a visible gray square ($25° \times 25°$), whereas the monitor subtended $36.6° \times 27.6°$. This chasing game was executed on PC monitors (resolution: 1024×768; refresh rate: 60 Hz) using custom software written in MATLAB with the Psychophysics Toolbox libraries (Brainard, 1997). Each group member manipulated a PC

[1] When more than one chaser is running, it is nearly impossible for an individual to be completely alone in a chase pursuing the same target. For instance, one agent occupies the possible positions of others, and to some extent, exhibits competitive chasing, which was observed in our study. Here, individual chasing means that the agents behave without coordination, or at least with less coordination, than found in coordinated chasing.