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The Facilitative Effect of Context on Second-Order Social Reasoning

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Abstract

This paper is about higher-order social reasoning such as "I think that you think that I think …". Previous research has shown that such reasoning seriously deteriorates in complex social interactions. It has been suggested that reasoning can be facilitated greatly if an abstract logical problem is embedded in a context. This has not yet been tested for higher-order social reasoning. We presented participants with strategic games that demand higher-order social reasoning. The games were embedded in the context of a marble game. Participants performed really well, that is, almost at ceiling. We argue that context has a facilitative effect on higher order-social reasoning.

Keywords: Theory of Mind; Social Cognition; Higher-order Social Reasoning; Strategic Game.

Social Reasoning

In many social situations we need to reason about one another. We do so to plan our actions and predict how our behavior might affect others. The ability to reason about another's knowledge, beliefs, desires and intentions is often referred to as Theory of Mind (Premack & Woodruff, 1978). It has been extensively investigated in children and seems to develop around the age of 4 years (Wimmer & Perner, 1983; but see Onishi & Baillargeon, 2005). Nevertheless, reasoning about others is very demanding, even for adults, which becomes apparent in more complex interactions. So far, empirical results have shown social reasoning to be far from optimal (Flobbe, Verbrugge, Hendriks, & Krämer, 2008; Hedden & Zhang, 2002). It has been suggested that (social) reasoning might be facilitated if it is embedded in a context (Wason & Shapiro, 1971). In the current study, we investigate whether social reasoning really is difficult and whether embedding it in a context can facilitate it.

When we ascribe a simple mental state to someone, we are applying first-order social reasoning. For example, imagine a social interaction between Ann, Bob and Carol. If Bob thinks "Ann knows that my birthday is tomorrow", he is applying first-order reasoning, which covers a great deal of social interaction.

However, first-order reasoning is not sufficient to cover more complex social situations. The interaction between Ann, Bob and Carol can easily demand reasoning of one order higher: If Carol thinks "Bob knows that Ann knows that his birthday is tomorrow", she is making a second-order attribution.

Bob's first-order attribution and Carol's second-order attribution are hierarchically structured: Bob applied first-order reasoning by attributing a mental state to Ann, and Carol applied second-order reasoning by attributing first-order reasoning to Bob. A third-order attribution involves the reader attributing second-order reasoning to Carol, and so forth.

The depth of reasoning in humans is constrained by cognitive resources (Verbrugge, 2009; Flobbe et al., 2008; Hedden & Zhang, 2002). As the order of reasoning increases, the demands on cognitive processing increase as well. Cognitive resources and processing speed seem to increase with age (Fry & Hale, 1996), and that increase could allow for the representation of increasingly more complex mental states. Findings from developmental studies support that idea. Where first-order social reasoning is acquired at the age of around 4 years (Wimmer & Perner, 1983), second-order social reasoning seems to develop some years later, at the age of around 6 to 8 years (Perner & Wimmer, 1985). However, 6- to 8-year-olds do not understand all kinds of mental states, and even adults cannot readily apply second-order reasoning in all kinds of contexts (Flobbe et al., 2008; Hedden & Zhang, 2002).

Paradigms to Test Social Reasoning

There are a few paradigms to test social cognition. Probably the most familiar paradigm is the False-Belief task (Wimmer & Perner, 1983), which has been adapted to test second-order social cognition (Perner & Wimmer, 1985). In a typical second-order False-Belief story, two characters, John and Mary, are independently informed about the transfer of an object, an ice-cream van, from one location to another. In the story, both John and Mary know where the van is, but John does not know that Mary also knows that the van has moved to a new location. Participants are told the story and asked where John thinks Mary will go for ice cream. To answer this question correctly, participants have to be able to represent the second-order false belief "John thinks that Mary thinks the van is still at the old location.". In Perner and Wimmer's (1985) study, some children of 6 to 7 years of age were able to make such second-order attributions, but only under optimal conditions; when the inference of second-order beliefs was prompted.

Apart from some concerns about the False-Belief task's aptness to test for the presence of a Theory of Mind (Bloom & German, 2000), Perner and Wimmer (1985) expressed concerns about the generality of their findings as participants were presented "rather pedestrian problem[s] of knowing where somebody has gone to look for something" (p. 469). They stressed that investigations into higher-order social reasoning will only achieve theoretical importance if a link with other domains can be established.

Various other language comprehension paradigms have been used to test social cognition (e.g., Van Rij, Van Rijn, & Hendriks, to appear; Hollebrandse, Hobbs, De Villiers, & Roeper, 2008; Hendriks & Spenader, 2006). Hollebrandse et al. (2008) presented discourse with multiple, recursive embeddings. In their Experiment 1, no second-order reasoning was observed in children and adults. Hollebrandse et al.'s (2008) findings led them to conclude that "second-order theory of mind is a different milestone than first-order theory of mind." (p. 276).

The problem with the paradigms mentioned above is that they depend heavily on language skills (Apperly, Samson, Chiavarino, & Humphreys, 2004; Bloom & German, 2000), and cannot be adapted easily to investigate higher orders of reasoning. A paradigm that does not depend that much on language skills is that of strategic games (Verbrugge, 2009; Flobbe et al., 2008; Hedden & Zhang, 2002). In strategic games, players have to reason about one another, because a player's payoffs depend on what the other players do, and vice versa. Games are less prone to semantic idiosyncrasies and are as such easier to control. That allows games to be presented repeatedly in different variations to acquire a more accurate measure of second-order reasoning.

Strategic Games

Hedden and Zhang (2002) used a strategic game to study first- and second-order social reasoning. It is a sequential-move game, which is played on a 2-by-2 matrix (Figure 1). In each cell there are separate payoffs for Player 1 and Player 2, respectively. The goal is to attain the highest possible payoff. The players take turns; Player 1 begins. At each turn, a player has to decide whether to stay or to move to the next cell, as indicated in Figure 1. If a player decides to stay in a particular cell, the game ends and both players attain the respective payoffs in that cell. If a player decides to move, the turn passes to the other player.

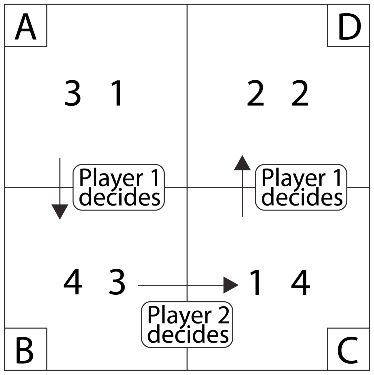


Figure 1: Schematic overview of a matrix game (Hedden & Zhang, 2002). The first number in each cell is Player 1's payoff, the second Player 2's payoff. The goal is to attain the highest possible payoff. Participants first had to predict what the other player would do at cell B before making a decision what to do at cell A. In this example, Player 1 would have to predict that Player 2 will stay, because Player 1 will move if given a choice at cell C, leading to a lower payoff for Player 2, namely 2 instead of 4. Consequently, the rational decision for Player 1 is to move to cell B.

Hedden and Zhang (2002) asked participants to (1) predict what the other player would do (stay or move) at cell B, and (2) decide whether to stay or to move at cell A. The first question provides a direct measure of what order of reasoning participants apply. To answer that question correctly, participants have to apply second-order reasoning; think about what the other player (at cell B) thinks that they think (at cell C). The second question measures whether the decisions that the participants make are based on the predictions that they have made. As a consequence of this procedure in which participants first have to predict what the other player will do, the application of second-order reasoning may not be completely spontaneous. Nevertheless, the proportion of games in which participants made second-order predictions is not that high, in the range of 60% – 70% at the end of the experiments 1 and 2, considering that by chance alone that proportion would be 50%, because there are just two predictions possible: either Player 2 stays or Player 2 moves.

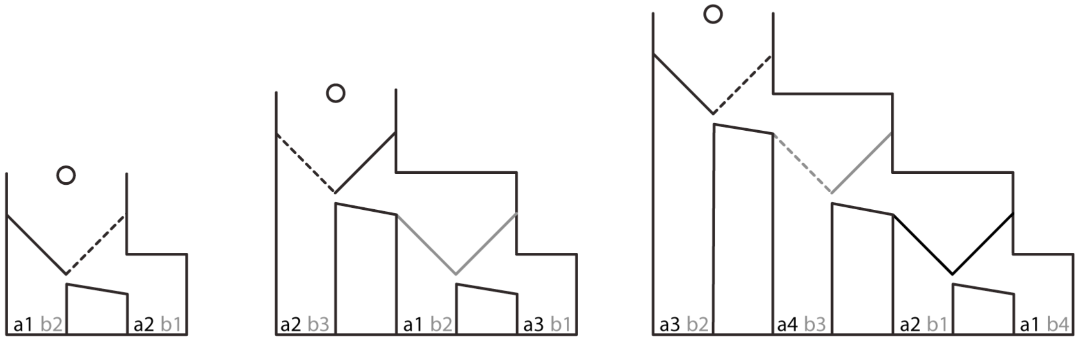
Poor performance could imply that second-order social reasoning is difficult or that participants had difficulties understanding Hedden and Zhang's (2002) matrix games. Participants could have had difficulties to comprehend the task, because the games are very abstract. The matrix games of Hedden and Zhang (2002) would be less abstract if embedded in a context. Higher-order social reasoning, which seems to be very demanding in these games, might benefit from a context embedding.

Context Effects

Some studies have investigated whether reasoning can be facilitated if a problem is presented in a (social) context. The Wason Selection Task (Wason & Shapiro, 1971) is an example of a task to investigate effects of context on reasoning. Wason and Shapiro (1971) presented a logical problem in an abstract form to one group of participants and in a "thematic" form (i.e., embedded in a social context) to another group of participants. Ten out of sixteen participants in the thematic group solved the problem, opposed to two out of sixteen participants in the abstract group. That finding implies a facilitative effect of context on reasoning.

However, there is another interpretation of Wason and Shapiro's (1971) manipulation, according to which the abstract and thematic forms are not logically equivalent (Stenning & Van Lambalgen, 2004; Manktelow & Over, 1991). If the logical problem does differ for these forms, Wason and Shapiro's findings do not support the argument that context has a facilitative effect on reasoning. To really appreciate facilitative effects of context on (higher-order social) reasoning, it is important that the context in which we embed the matrix games of Hedden and Zhang (2002) does not change their logical form. Then, improved performance can be attributed solely to context effects.

Not just any context will facilitate (higher-order social) reasoning. Flobbe et al. (2008) embedded Hedden and Zhang's matrix games in a context. Participants played games in which they, together with the computer, drive a car. The games are an adaptation of the Centipede game (Rosenthal, 1981), and are logically equivalent to Hedden and Zhang's (2002) matrix games. In second-order games,



(a) (b) (c)

Figure 2: A zeroth-order (a), first-order (b) and second-order (c) Marble Drop game. The participant's payoffs are represented by a1 – a4, the computer's by b1 – b4, both in increasing order of value. The goal is to let the white marble end up in the bin with the highest attainable payoff. The diagonal lines represent trapdoors. At the first set of trapdoors, the participant decides which of both trapdoors to remove, at the second set the computer decides, and at the third set the participant again decides. The dashed lines represent the trapdoors that both players should remove to attain the highest payoff they can get.

the road has three junctions, which correspond with the transitions, from one cell to another, in Hedden and Zhang's matrix games. At each junction either the participant or the computer decides to move ahead (i.e., continue the game) if there is a higher payoff to attain further in the game, or to turn right (i.e., end the game) if there is no higher payoff to be attained further in the game. The participant and the computer alternately take seat in the driver's position; the one in driver's seat makes the decision.

The performance of the adult participants in Flobbe et al.'s experiment was higher than in Hedden and Zhang's study: the mean proportion of games in which the adult participants gave a correct second-order prediction was more than 70%. It is important to note that this proportion is an average over Flobbe et al.'s entire experiment, whereas in Hedden and Zhang's experiments the proportion of games in which the participants applied second-order reasoning did not reach 60% – 70% until the end.

Flobbe et al.'s findings support the idea that context facilitates reasoning. Their findings also show, as did Hedden and Zhang's, that second-order reasoning is not impossible. However, performance was low, considering that the participants were explicitly asked to reason about their opponent. Both Flobbe et al. and Hedden and Zhang asked participants to first make a prediction before making a decision. This procedure is expected to scaffold second-order reasoning, as it prompts the participants to think about the other player (and what that player might think of them).

We expect that performance can be much further improved with a simpler context. In Flobbe et al.'s task, participants alternately change driver's seat with another player, which is not common practice in every day life. In the next section we will present a context that is more intuitive and will require less explanation.

We argue that second-order reasoning is not that difficult if it is embedded in an apt context, and that the facilitative effects of context render the scaffolding effects of making predictions (before making a decision) obsolete.

Experiment: Marbles and Second-order Reasoning

We present games, which we will call Marble Drop, in which the path of a white marble, which is about to drop, can be manipulated by removing trapdoors (Figure 2). Experience with world-physics allows players to see easily how the marble will run through a game. The interface of the game is very insightful; players can quickly see who can change the path of the marble, at what point in the game.

Marble Drop games are logically equivalent to Hedden and Zhang's (2002) matrix games and Flobbe et al.'s (2008) Centipede games (which we show with an informal proof in http://www.ai.rug.nl/~leendert/Equivalence.pdf). Marble Drop games only differ in appearance. The payoffs are color-graded marbles, which can easily be ranked according to preference, lighter marbles being less preferred than darker marbles. The ranking makes it possible to have payoff structures similar to those in matrix and Centipede games. The sets of trapdoors in Marble Drop games correspond with the transitions, from one cell to another, in Hedden and Zhang's (2002) matrix games.

We used color-graded marbles instead of numbers (of marbles) to minimize the usage of numeric strategies other than first- and second-order reasoning. We observed such alternative strategies in pilot studies in which we presented Flobbe et al.'s (2008) Centipede games with payoff numbers. Participants reported to use strategies such as maximizing the difference in both players' payoffs, maximizing the sum of both players' payoffs, and obstructing the other player.

Figure 2 depicts example games of Marble Drop. The goal is to let the white marble end up in the bin with the darkest color-graded marble. Note, for illustrative purposes, the color-graded marbles are replaced with codes: a1 – a4 represent the participants' color-graded marbles and b1 – b4 represent the computer's color-graded marbles (which are of another color); 1 – 4 being light to dark grades. (See http://www.ai.rug.nl/~meijering/MarbleDrop.html for the original Marble Drop games.) The diagonal lines represent the trapdoors.

In the example game in Figure 2a, participants need to remove the right trapdoor to attain the darkest color-graded marble of their color (a2). The game in Figure 2a is a zeroth-order game, because there is no other player to reason about.

In first-order games (Figure 2b) participants need to reason about another player, the computer. The computer is programmed to let the white marble end up in the bin with the darkest color-graded marble of its target color, which is different from the participants' target color. Participants need to reason about the computer, because the computer's decision at the second set of trapdoors affects at what bin a participant can end up.

In the example game in Figure 2b, if given a choice at the second set of trapdoors, the computer will remove the left trapdoor, because its marble in the second bin (b2) is darker than its marble in the third bin (b1). Consequently, the participant's darkest marble in the third bin (a3) is unattainable. The participant should therefore remove the left trapdoor (of the first set of trapdoors), because the marble of their target color in the first bin (a2) is darker than the marble of their target color in the second bin (a1).

In a second-order game (Figure 2c) there is a third set of trapdoors at which the participants again decide what trapdoor to remove. They need to apply second-order reasoning, that is, reason about what the computer, at the second set of trapdoors, thinks that they, at the third set of trapdoors, think.

Method

Participants Twenty-two Psychology students participated in exchange for course credit. Two were excluded because of not adhering to the instructions.

Stimuli The colors of the marbles were taken from the HSV (hue, saturation and value) space. A sequential color palette was computed by varying saturation, for a given hue and value. This resulted in 4 grades (with saturation from 1 to .2) for each of the colors orange (hue = .1, value = 1) and blue (hue = .6, value = 1).

The payoff structures are constructed to be diagnostic of second-order reasoning. First- and second-order reasoning should yield opposite predictions and decisions in order to allow us to see at what order participants are reasoning.

All payoff structures in the experiment demand second-order reasoning. Consequently, payoff structures in which Player 1's first payoff is a marble with a color gradient of 1 or 4 are excluded. It is evident that in the former case participants should continue the game and in the latter case participants should end the game, whatever the other player does. The same holds for Player 2's second payoff, because at that bin (underneath the second set of trapdoors), Player 2 decides what to do.

Also, payoff structures in which Player 2's payoffs in bins 3 and 4 are lower or higher than the payoff in bin 2 are excluded. Player 2 does not need to consider Player 1's payoffs in these structures.

The payoff structures are doubly balanced for the number of left/right (trapdoor removal) predictions about Player 2 and decisions of Player 1.

Design & Procedure Before the experiment took place, participants were tested on colorblindness. They had to be able to distinguish the two colors blue and orange, and the 4 grades of each color. The experiment consisted of 3 blocks: a training block, an experimental manipulation block, and a test block.

The training block consists of zeroth-, first- and second-order Marble Drop games, respectively. In zeroth-order games, participants do not have to reason about another player. They have to find out in what bin the darkest color-graded marble of their target color is, and what trapdoor to remove to let the white marble end up in that bin. The target color is either blue or orange, which is counterbalanced between participants. If a participant's target color is blue, the computer's target color is orange, and vice versa. These games do not require social reasoning but are presented to familiarize the participants with the physics of the Marble Drop game. Participants are presented 4 zeroth-order games.

We assume that in first- and second-order games, participants reason about the decision of the computer at the second set of trapdoors. If a participant removes the left trapdoor of the first set of trapdoors, the white marble will drop into the first bin. If a participant removes the right trapdoor of the first set of trapdoors, the white marble will roll to the second set of trapdoors at which the computer decides what trapdoor to remove. If the computer removes the left trapdoor, the white marble will drop into the second bin. If the computer removes the right trapdoor, the white marble will drop into the third bin in first-order games, it will roll to the third set of trapdoors in second-order games. In the latter case, the turn passes to the participant. If the participant removes the left trapdoor, the white marble will drop into the third bin. If the participant removes the right trapdoor, the white marble will drop into the fourth bin. As soon as the white marble drops into a bin, participants are presented feedback ("correct!" or "incorrect!"). If they fail to let the white marble end up in the correct bin, a green arrow is depicted underneath the correct bin and participants are asked to explain verbally why that bin is the correct one. Participants are presented 8 first-order games and 8 second-order games.

In the experimental manipulation block, participants play second-order Marble Drop games. The participants are asked to decide what to do at the first set of trapdoors. They immediately receive feedback after making a decision. The experimental manipulation involves that one half of the participants is asked first to predict what the computer will do at the second set of trapdoors, before making a decision at the first set of trapdoors. This manipulation is included to investigate scaffolding effects of making predictions. In this block and the next, the games are not continued after the participants have made a decision. The experimental manipulation block consists of 32 trials, all trials diagnostic of second-order social reasoning.

In the test block, the participants play second-order Marble Drop games. The participants that made a prediction before making a decision in the experimental manipulation block do not have to make predictions anymore. The test block has the same structure as the experimental manipulation block, except that none of the participants have to make predictions anymore.

The participants were randomly assigned to the group that makes a prediction and a decision in the experimental manipulation block and only a decision in the test block, the PD-D group, and the group that makes decisions in the experimental manipulation and the test block, the D-D group.

Results

To account for random effects of individual differences and payoff structures, we performed Linear Mixed-Effects (LME) analyses (Baayen, Davidson, & Bates, 2008). We first analyzed the proportion of games in which participants applied second-order reasoning (Figure 3). The analysis consists of a (logistic) LME with *block* (*experimental manipulation* and *test*) and *group* (*PD-D* and *D-D*) as fixed factors and *participants* and *payoff structures* as random factors.

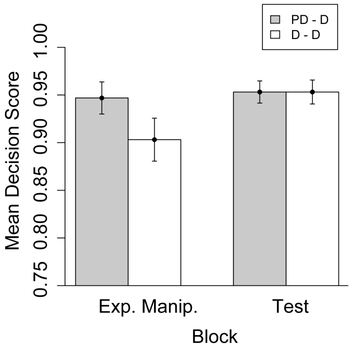


Figure 3: Mean proportion of games in which participants applied second-order reasoning, presented separately for the PD-D and D-D groups in the experimental manipulation block and the test block. The standard errors are depicted above and below the means.

The grand mean is 0.94. The factors *block* and *group* are significant: β = .809, z = 2.348, p = .009 and β = 5.721, z = 1.844, p = .033, respectively. The interaction *group* x *block* is also significant: β = -1.024, z = -1.844, p = .033.

Reaction Times The games in the experimental manipulation block are procedurally different for the PD-D and the D-D groups. We analyzed the reaction times of the games in the test block, because these are not procedurally different for the PD-D and the D-D groups.

After removing the trials in which participants unsuccessfully applied second-order reasoning, a LME analysis was performed, with *group* (*PD-D* and *D-D*) as a fixed factor and *participants* and *payoff structures* as random factors.

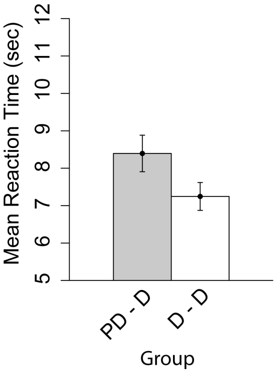


Figure 4: Mean reaction times for the PD-D and D-D groups. The standard errors are depicted above and below the means.

The grand mean is 7.82 seconds. The factor *group* is significant: β = 1.523, t = 3.09, p < .01. On average, the participants in the D-D group were faster to make a decision than the participants in the PD-D group (Figure 4).

Discussion

The participants performed really well in the Marble Drop games (Figure 3). The proportion of games in which they successfully applied second-order reasoning was very high, at 94% correct. That proportion is much higher than in Hedden and Zhang's (2002) matrix games (60% - 70%) and Flobbe et al.'s (2008) Centipede games (slightly above 70%). This finding supports the idea that a context can facilitate reasoning. It matters in what context reasoning is embedded. Flobbe et al.'s context facilitated higher-order reasoning, but not as strongly as in our experiment, which has a simpler context.

The interaction between *block* and *group* is significant. The performance of the participants that made a prediction before making a decision in the experimental manipulation block, the PD-D group, is almost at ceiling in both the experimental manipulation block and the test block (Figure 3). On the other hand, the performance of the participants that did not make a prediction in the experimental manipulation block, the D-D group, is not yet at ceiling in the experimental manipulation block, but reaches ceiling in the test block (Figure 3). This finding could imply that the D-D group lacked a scaffolding effect of making predictions in the beginning of the experiment. However, the D-D group, which was not explicitly asked to predict what the other player would do (before making a decision), probably did learn to make predictions during the experimental manipulation block. Eventually, there was no difference in performance anymore in the test block.

The main effect of *block* can be mainly attributed to the D-D group. The performance of the participants in the D-D group increases to ceiling in the test block, whereas the performance of the participants in the PD-D groups already reaches ceiling in experimental manipulation block and remains stable (Figure 3).

The participants not only performed better, they also responded faster in Marble Drop games than in matrix games. Mean reaction times of second-order predictions were approximately 10 seconds in matrix games (Hedden & Zhang, 2002), whereas mean reaction times of second-order predictions took less than 7.5 (M = 7.1, SE = .57) seconds in Marble Drop games for the PD-D group in the experimental manipulation block. Mean reaction times of second-order decisions (based on second-order predictions) were approximately 3.5 second in matrix games, and less than 2.5 (M = 2.2, S = .77) seconds in Marble Drop games for the PD-D group in the experimental manipulation block.

Although these comparisons with Hedden and Zhang's (2002) results are informal, the differences are considerable. The better performance in Marble Drop games than in Hedden and Zhang's (2002) matrix games probably is not caused by a difference in our participants' speed-accuracy tradeoff. Our participants applied second-order reasoning more often and faster, which supports the idea that our context facilitated higher-order reasoning.

In the test block, on average, the participants in the D-D group were faster to make a decision than the participants in the PD-D group (Figure 4). In the test block, the behavior of the participants in the PD-D group could still have been constrained in a stepwise procedure of first making a prediction, then a decision. The participants in the D-D group were given more freedom in the experimental manipulation block to naturally interleave a prediction between the steps in their decision-making, which could have caused them to be faster than the participants in the PD-D group.

General Conclusion

Our findings seem to imply that embedding a logical problem in a context greatly facilitates (social) reasoning. Because of the facilitative effects of context embedding, second-order reasoning did not need to be scaffolded by explicitly asking participants to predict the behavior of other players. Second-order reasoning might still be difficult, but participants were able to apply it in Marble Drop games.

The question remains what strategies participants used to arrive at second-order decisions and predictions. We intend to investigate this with computational models (e.g., Van Maanen & Verbrugge, submitted). These models can help us to explore the cognitive mechanism involved in higher-order social cognition, and whether higher-order social cognition will generalize to more complex tasks.

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