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Supporting Online Material for

The Social Sense: Susceptibility to Others' Beliefs in Human Infants and Adults

Ágnes Melinda Kovács,* Ernő Téglás, Ansgar Denis Endress

*To whom correspondence should be addressed. E-mail: agneskovacs@mtapi.hu

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Supporting Online Material

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6. Detailed results for Experiment 4 to 7 (infants).

1. Materials and methods for Experiments 1 to 3 (adults)

1.1. Experiment 1 (adults)

1.1.1. Participants

Twenty-four right-handed adults (15 females, mean age 22, range 19–28) took part in Experiment 1. Participants were tested at the Language, Cognition and Development Lab, SISSA, Trieste (Italy), and received monetary compensation. Participants did not take part in any other experiment reported in this paper.

1.1.2. Materials and Procedure

Participants watched 40 18.4s long animated movies, generated using Maya 3D software. The movies involved an agent, a ball and an occluder placed on a table. There were four belief conditions, each paired with 2 different outcomes (ball present/ball absent), resulting in 8 different movies, each seen 5 times. Our critical manipulations involved the beliefs of the participant about the ball's presence and the "beliefs" of the agent. This was achieved by varying the final location of the ball before the occluder was lowered, and the time at which the agent left the scene. Specifically, the agent left the scene either before the ball reached its final location or afterwards. In the last scene of the movie, the agent returned and the occluder was lowered; participants were instructed to press a button as soon as they detected the ball after the occluder was lowered. We recorded their reaction times.

All movies in all experimental conditions had four phases. The first phase and the last phase of the movies (columns 1 and 4 in Fig. 1) were physically identical in each of the four conditions, and had durations of 5s and 3s, respectively. In the last phase of all conditions the agent came back to the scene at 16s. The second and the third phases, in contrast, differed across the four conditions. The following descriptions refer to these two phases.

In the P+A+ condition, the ball rolled out of the scene from behind the occluder, and then rolled back behind the occluder (ball last seen by the participant at 12s; time information is given relative to the beginning of the movie), all in the agent's presence. The agent left the scene at 14s. Thus, the participant (P) and the agent (A) both believed the ball to be behind the occluder (P+A+).

In the P-A- condition, the ball emerged from behind the occluder without leaving the scene, then rolled back behind the occluder, and finally left the scene (ball last seen at 12s), all in the agent's presence. The agent left the scene at 14s. Thus, neither the participant nor the agent believed the ball to be behind the occluder (P-A-).

In P-A+ condition, we reversed the order of when the ball and the agent left the scene, relative to the P-A- condition. Thus, the agent left the scene at 8s. The ball then emerged from behind the occluder without leaving the scene, rolled back behind the occluder, and finally left the scene (ball last seen at 14s), all in the agent's absence. Thus, only the agent but not the participant believed the ball to be behind the occluder (P-A+).

In the P+A- condition, the ball rolled out of the scene from behind the occluder in the agent's presence. Then, the agent left the scene at 11s. In his absence, the ball rolled back behind the occluder at 14s. Thus, only the participant but not the agent believed the ball to be behind the occluder (P+A-).

As a result of the design (true belief/false belief), the experimental conditions involved differences in the ordering of the events, as well as differences in the relative times when the agent left the scene and when the ball was last seen. The ordering differences resulted from our experimental design, in which some conditions required the agent to leave the scene *before* the ball reached its final location (resulting in a false belief), and other conditions required the agent to leave *after* the ball reached its final location (resulting in a true belief).

To control for the timing differences, we used pairs of conditions matched for their timing properties. (It was not possible to use 4 conditions with exactly the same timing properties as a result of the design.) Specifically, in the two true belief conditions (P+A+

and P-A-), participants last saw the ball at 12s after the start of the movie. In the two false belief conditions (P-A+ and P+A-), participants last saw the ball at 14s. We controlled in the same way for the time-point at which the ball was in the vicinity of the occluder, operationally defined as the last moment at which the ball crossed the midline between the right edge of the occluder and the right edge of the computer screen. In the two true belief conditions, the ball was in the vicinity of the occluder at 11s, while the ball was in the vicinity of the occluder at 13s in the two false belief conditions.

In all conditions, the ball covered the same total visible distance, and rolled twice behind the occluder. In 50% of the trials in all four conditions (20 trials in total), a ball was revealed behind the occluder when the occluder was lowered at the end of the movie.

Participants were not informed about the purpose of the studies in advance; rather, they were simply told to perform a visual detection task. Participants were instructed to press a button with their right hand as soon as they detected the ball when the occluder was lowered. To make sure that they paid attention to the entire movie (and not just to the outcome), they were also instructed to press a button with their left hand when the agent left the scene.

Participants were tested individually in a sound-attenuated booth using Psyscope X (http://psy.ck.sissa.it/) on an Apple PowerBook. Responses were collected on a button box. Before starting the experiment, participants were given four practice trials with feedback; these trials were not included in the analysis.

1.2. Experiment 2 (adults)

1.2.1. Participants

Twenty-four right-handed adults (14 females, mean age 22, range 18–31) took part in Experiment 2. They were tested at the Language, Cognition and Development Lab, SISSA, Trieste (Italy), and received monetary compensation. Participants did not take part in any other experiment reported in this paper.

1.2.2. Materials and Procedure

Experiment 2 was identical to Experiment 1, except that, in the last phase of all conditions (column 4 in Fig. 1), a pile of boxes entered the scene instead of the agent. That is, in all four conditions, the agent was present in the initial phases of the movies corresponding to columns 1 to 3 in Fig. 1. As a result, the agent could witness the movements of the ball either fully or in part (depending on the condition); and participants could compute his belief about the presence or absence of the ball behind the occluder. However, when participants had to give their response (column 4 in Fig. 1), the agent was never present, and was replaced with a pile of boxes.

Participants were not informed about the purpose of the studies in advance; rather, they were simply told to perform a visual detection task. Although they were not formally debriefed at the end of the study, those who reported their thoughts either said that they believed the agent and the boxes to be irrelevant, or that the agent and the boxes were distractors, and that we used them to make the visual detection task harder. In Experiment 2, none of the participants (all of whom never saw the agent return or have contact with the boxes) reported perceiving any relation between the boxes and the agent.

1.3. Experiment 3 (adults)

1.3.1. Participants

Twenty-four right-handed adults (15 females, mean age 23, range 20–32) took part in this experiment. Participants were tested at the Language, Cognition and Development Lab, SISSA, Trieste, or at the Cognitive Science Lab, Budapest University of Technology; our crucial comparisons involved within-subject comparisons. Participants received monetary compensation or course credit for participation. They did not take part in any other experiment reported in this paper.

1.3.2. Materials and Procedure

Materials and procedure were similar to those shown in Experiments 1 and 2, except that the agent did not appear in the movies *at all*. Instead, a stationary pile of boxes (represented by B in the condition labels) was present in all the movies during their entire duration. However, the ball followed the exact same paths as in Experiments 1 and 2. Hence, while participants in this experiment could not compute another agent's beliefs because no agent was present, they experienced motion paths of the ball identical to those in the different belief conditions of Experiments 1 and 2.

2. Further analyses of Experiments 1 and 2

As a result of the experimental manipulation (true belief/false belief), our conditions differed in the ordering of the different events, that is, in how many events occurred between the last moment at which participants represented the ball behind the occluder, and the moment at which they had to detect the ball. Specifically, there were two intervening events in the P+A+ condition (agent leaves, agent returns) and the P-A+ condition (ball

leaves, agent returns); one intervening event in the P+A- condition (agent returns); and three intervening events in the P-A- condition (ball leaves, agent leaves, agent returns).

If reaction times are driven by the number of intervening events, conditions with more intervening events should show longer RTs, leading to the following predictions. First, reaction times in the P+A+ condition should be slower than in the P+A- condition. Results of Experiments 1 and 2 show that this is not the case; reaction times do not differ significantly between these conditions (Experiment 1: $t(23)=1.03$, $p=0.31$; Experiment 2: $t(23)=1.16$, $p=0.25$), and RTs were numerically faster in the P+A+ condition. Second, such an account would predict that reaction times in the P+A- condition should be faster than in the P-A+ condition. This prediction is not supported by the data either, as reaction times did not differ significantly between these conditions (Experiment 1: $t(23)=0.99$, $p=0.33$; Experiment 2: $t(23)=1.74$, $p=0.09$, with RTs numerically faster in the P-A+ condition). Hence, an account based on the number of intervening events does not seem to explain our data in the four experimental conditions.

3. Detailed results of Experiment 3

Participants were faster in the two conditions in which they believed the ball to be behind the occluder than in the two conditions in which they did not believe so (P+B[+] vs. P-B[+]: $t(23)=2.29$, $p=0.03$; P+B[+] vs. P-B[-]: $t(23)=2.42$, $p=0.02$; P+B[-] vs. P-B[+]: $t(23)=2.37$, $p=0.02$; P+B[-] vs. P-B[-]: $t(23)=2.18$, $p=.04$). There was no difference between the P+B[+] and the P+B[-] conditions (P+B[+]: $M=403$ms, $SD=61$ms; P+B[-]: $M=407$ms, $SD=64$ms), with no difference between these conditions ($t(23)=0.4$, $p=0.68$).

We followed up the non-significant results with likelihood ratio analyses, which allow us to provide evidence *for* a non-significant null hypothesis (S1). Likelihood ratios

were computed for the (within-subject) differences between these conditions. The null model was a normal distribution with a mean of 0 and a free parameter for the standard deviation; the alternative model comprised an additional free parameter for the mean. Likelihood ratios strongly favored the null hypothesis (likelihood ratio in favor of the null hypothesis after correction with the Bayesian Information criterion (BIC): 4.51; after correction with the Akaike Information Criterion (AIC): 3.04).

Importantly, there was no difference between the P-B[+] and the P-B[-] conditions (P-B[+]: M=426ms, SD=65ms; P-B[-]: M=420ms, SD=65ms; $t(23)=0.76$, $p=0.45$), corresponding to the critical false belief contrast between the P-A+ and P-A- conditions in Experiments 1 and 2. A likelihood ratio analysis favored the null hypothesis (likelihood ratio after BIC correction: 3.65; after AIC correction: 2.46).

That is, when no agent was present, participants' RTs were influenced only by their own beliefs about the presence of the ball, but not by other perceptual differences between the conditions.

4. Replication of Experiment 1 with modified ball movements

Due to our design, the time point at which participants in Experiment 1 last saw the ball differed between the P-A+ and the P-A- condition. We replicated these two conditions, using modified movies such that participants last saw the ball at 14s in both conditions; likewise, the ball was in the vicinity of the occluder (as defined above) at 13s in both conditions.

Participants watched 40 movies that were 20.4s long. The materials and procedure were identical to those in Experiment 1, except that participants last saw the ball at 14s in both the P-A+ and the P-A- conditions. Sixteen right-handed adults (7 females, mean age

21, range 18–26) completed the experiment. They were tested at the Cognitive Science Lab, Budapest University of Technology (Hungary), and received course credit for participation. Participants took part in no other experiment reported in this manuscript.

Results from this experiment replicate the main finding from Experiment 1. Participants displayed faster RTs in the condition where only the agent believed that the ball was behind the occluder (P-A+: M=332ms, SD=53ms) compared to the condition where neither the participant nor the agent believed the ball to be behind the occluder (P-A-: M=357ms, SD=76ms), $t(15)=2.65$, $p=0.01$. Thus, as in Experiment 1, participants in this experiment automatically computed the agent's belief, and this belief influenced their behavior even though it was inconsistent with their own belief.

5. Materials and methods for Experiments 4 – 7 (infants)

5.1. Participants

Fifty-six healthy full-term infants (mean age 7 months, 18 days, range 7.05 – 7.30, 27 girls) were randomly assigned to Experiments 4 to 7 (N=14 in each experiment). An additional 18 infants were excluded because of crying or fussiness. Parents gave informed consent prior to the experiments. Infants were tested at SISSA, Language, Cognition and Development Lab, Trieste (Italy).

5.2. Apparatus

Infants were tested using a violation of expectation procedure. They were seated on a caretaker's lap in a dimly lit, sound-attenuated booth 60cm away from the monitor used to display the stimuli. The caretaker wore opaque glasses throughout the experiment. The experiment was controlled by Psyscope X. The experimenter, who was blind to

experimental condition, controlled the experiment and monitored infants' behavior from a separate screen.

To ensure that each infant attended to each movie for its entire duration, the stimulus presentation was infant-controlled. That is, movies were paused if and when infants looked away from the screen. Infants' looking behavior was recorded using a camera hidden behind the monitor and coded off-line.

5.3. Materials and Procedure

In all experiments, infants first saw two identical familiarization movies, each lasting for 11s. In these movies, the agent placed the ball on the table, and the ball rolled behind the occluder. At the end of the movie, the occluder was lowered, revealing the ball. Following familiarization, infants were exposed to two test movies, taken from Experiment 1 or 2. Importantly, when the occluder was lowered at the end of the test movies, no ball was revealed in any of the test movies. The rationale for this dependent measure was that previous studies suggested that infants' looking behavior may be more strongly affected by the unexpected disappearance of objects compared to the unexpected appearance of objects (*S2, S3*), although infants may respond to unexpected appearances under specific circumstances (*S4*). The order of the test movies was counterbalanced across infants. The movies were stopped at the last frame, which remained on the screen until the infant looked away for two consecutive seconds, or up to a cumulative looking time of 30s.

In Experiment 4, we validated the procedure as a violation of expectation paradigm. Infants were presented with the movies from the P+A+ condition and the P-A- condition of Experiment 1. In Experiment 5, infants saw the movies from the P-A+ condition (Movie

S1) and the P-A- condition. In Experiment 6, as in Experiment 5, they saw the movies from the P-A+ condition and the P-A- condition; however, the occluder was *not* lowered at the end of the movies. As a result, neither the infant's nor the agent's beliefs were confirmed or disconfirmed. In Experiment 7, participants were presented with the movies from the P-A+ condition and the P-A- condition from Experiment 2, in which a pile of boxes entered the scene instead of the agent before the occluder was lowered.

6. Detailed results for Experiments 4 to 7 (infants)

6.1. Experiment 4

An ANOVA with presentation order (P-A- condition first vs. P-A- second) as a between-subject factor and Condition (P+A+ vs. P-A-) as a within-subject factor yielded a significant main effect of Condition, $F(1,12)=5.13$, $p=0.04$, but no other main effects or interactions. When the occluder revealed no ball, infants looked longer in the P+A+ condition (M=13.65s, SD=7.74s) than in the P-A- condition (M=8.71s, SD=5.33s), suggesting that their beliefs about the presence of the ball modulated their looking behavior. Moreover, 12 out of 14 infants looked longer in the P+A+ condition than in the P-A- condition, $p(N=14)=0.007$ (binomial test).

6.2. Experiment 5

An ANOVA with presentation order (P-A- condition first vs. P-A- second) as a between-subject factor and Condition (P-A+ vs. P-A-) as a within subject-factor yielded a significant main effect of Condition, $F(1,12)= 7.18$, $p= 0.02$, but no other main effects or interactions. When the occluder revealed no ball, infants looked longer in the P-A+ condition (M=16.33,

SD=7.85s) than in the P-A- condition (*M*=11.52s, *SD*=6.54s), suggesting that the beliefs of the agent modulated the infants' looking behavior. Moreover, 11 out of 14 infants looked longer in the P-A+ condition than in the P-A- condition, p(N=14)=0.032 (binomial test).

6.3 Experiment 6

An ANOVA with presentation order (P-A- condition first vs. P-A- second) as a between-subject factor and Condition (P-A+ vs. P-A-) as a within-subject factor yielded no main effect of Condition, $F(1,12)= 0.05$, $p= 0.82$, no effect of order, and no interaction between these factors. When there was no outcome (the occluder was not lowered), infants looked equally long in the P-A+ condition (*M*=8.66, *SD*=4.19) and in the P-A- condition (*M*=9.02, *SD*=5.3) because neither conditions violated the beliefs of the infant or the agent. 6 out of 14 infants looked longer in the P-A+ condition than in the P-A- condition, p(N=14)=0.59 (binomial test).

To compare Experiments 5 (False Belief) with Experiment 6 (No Outcome Control), we performed an ANOVA with Experiment as a between-subject factor and Condition (P-A+ vs. P-A-) as a within-subject factor. While there was no significant main effect of Condition, $F(1,26)=3.61$, $p=0.068$, ns, we observed a main effect of Experiment, $F(1,26)=5.63$, $p=0.02$, and, crucially, an interaction between these factors, $F(1,26)=4.88$, $p=0.03$.

6.4. Experiment 7

An ANOVA with presentation order (P-A- condition first vs. P-A- second) as a between-subject factor and Condition (P-A+ vs. P-A-) as a within-subject factor yielded a significant main effect of Condition, $F(1,12)= 6.26$, $p= 0.027$ (P-A+: *M*=12.73, *SD*=8.63; P-A-:

M=7.95, *SD*=3.97), but no other main effects or interactions. Moreover, 11 out of 14 infants looked in the P-A+ condition than in the P-A- condition, $p(N=14)=0.032$ (binomial test).

References Supporting Online Material

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