Supplementary Materials

S1. Sample video clips

Sample introductory clip: S1a_Introduction.mpg

Sample false belief condition with reach for true location: S1b_FalseBelief_t.mpg

Sample false belief condition with reach for original location: S1c_FalseBelief_o.mpg

Sample direct perception condition: S1d_DirectPerception.mpg

Sample true belief condition: S1e_TrueBelief.mpg

S2. Average event start times per condition

Event	False Belief	Direct Perception	True Belief
Video Begins	0.0	0.0	0.0
Panda faces object	0.1	0.0	0.3
Panda grabs object	1.3	1.3	1.5
Panda places object in box	2.1	2.0	2.5
Panda closes lid of boxes	4.3	4.5	4.8
Panda faces forward/audience	6.1	6.1	6.6
Actress becomes distracted	8.2	9.1	N/A
Panda relocates object	10.8	11.3	8.8
Panda closes lid of boxes	18.1	18.6	17.4
Panda faces forward/audience	21.4	22.1	21.1
Panda leaves scene	23.4	24.4	23.6
Actress faces forward/audience	25.4	26.0	N/A
Reach window illuminates	26.8	27.4	25.1
Actress shifts gaze (left or right)	29.9	30.0	28.3
Actress reaches for object	31.5	31.5	30.3
Actress retrieves object or removes empty hand from the box	36.1	36.3	34.9
Video pauses	37.3	37.4	36.3
Total Duration of Video	**42.0**	**42.0**	**42.0**

Event start times shown were calculated for each of the four actresses and averaged by condition by primary coder and then by another research assistant naïve to the hypothesis of the experiment.

S3. MNI coordinates for middle of active source detector pairs for each subject

Gender	Head CC*	MNI Position of Channel Pair Center (*x y z*)							
		A1	**A2**	**A3**	**B2**	**B3**	**B4**	**D7**	**D8**
F	54.5	47 -46 22	57 -46 21	51 -49 -1	67 -41 18	73 -48 -2	73 -28 12	55 38 25	38 37 11
F	56.5	52 -68 30	50 -48 25	54 -62 2	59 -43 18	56 -41 0	72 -38 13	47 22 22	42 46 23
F	55.0	54 -67 31	57 -53 27	61 -66 8	69 -48 24	56 -41 -1	73 -38 20	47 22 22	43 30 18
M	58.5	62 -58 39	60 -46 25	68 -54 11	62 -38 19	61 -43 2	73 -22 16	51 37 24	30 46 19
M	59.5	57 -66 40	46 -43 26	46 -47 16	46 -42 21	47 -38 8	68 -25 19	53 37 29	30 40 23

*Head circumference values are in centimeters

S4. Further Methodological Notes

Further details on pre-experiment measurements and participant rejections. Because psychology extra-credit participation for our experiments was constrained to 50 minutes and our experiments lasted about 40 minutes, potential participants for whom reasonable signal strengths could not be obtained in about 5 minutes after placing the probe, usually as a result of having extremely thick, braided, and/or dark hair, were dismissed before completing the experiment and not included in the fNIRS analysis or total participant count.

Line of open-ended questioning. After watching the videos, we asked some participants what they thought the experiment was about. Our line of questioning and answer coding followed from the first three questions asked by Schneider and colleagues (2012, 2014). We coded responses for use of mental state terms.

1. What did you think the purpose of the study was?
2. What did you notice was happening in the videos?

S5. Independent verification of free-viewing theory of mind stimuli with eye-tracking.

Overview

Input from colleagues suggested the potential need to verify that our stimuli evoked similar behavioral anticipatory looking patterns as have been found by several previous studies of spontaneous theory of mind (e.g. Schneider et al., 2014; Southgate et al., 2007). To address this matter, we conducted an eye-tracking study.

Method

Participants. Twenty-four adult participants (15 female; M age = 18.6, SD age = 0.82) between the ages of 18 and 21 were recruited through the University of Illinois psychology study pool. All participants provided written informed consent and received course credit for their participation

Procedure and Materials. Participants were centrally seated approximately 24 inches from a 27-inch LCD monitor (screen resolution: 1366 x 768). An eye-tracking device (The Eye Tribe, Copenhagen, Denmark) was placed below the monitor and pointed to the participant. Once seated, subjects completed the system standard 9-point calibration session. Calibration was considered successful when the average error was below 1 degree of visual angle, where 1-degree accuracy on a screen at a distance of 24 inches corresponds to an error of approximately 10-11 mm.

During testing, X and Y coordinates of eye gaze were continually recorded at a rate of either 30 (n = 17) or 60 Hz (n = 7) while adult participants freely viewed the same silent video clips (of an actress interacting with a puppet and objects) presented during our spontaneous theory of mind fNIRS task. Stimuli were presented from a PC laptop computer using E-Prime 2 (Psychology Software Tools, Sharpsburg, PA, USA). Subjects were simply instructed to pay close attention to the videos presented, as they would be questioned afterwards.

After the eye-tracking experiment was complete, participants were given a six-item questionnaire to determine the extent to which they may have been explicitly reasoning about mental states. Questions were taken and modified from a questionnaire as has been used in previous eye-tracking and neuroimaging studies of spontaneous theory of mind (see Schneider et al., 2014). Specifically, questions progressed from a completely open-ended question regarding the nature of the experiment to increasingly leading questions about the possibility that the experiment could be about mental states (see Supplemental Table S5-1). Answers were coded for the use of belief-mental state terms. Given that the last two questions could easily clue participants to interpret or reinterpret previously viewed stimuli in terms of mental states, only the first four open-ended questions were used as criteria for potential inclusion in the analysis.

Data processing and analysis. Eye gaze data were first converted to a common time scale, milliseconds from the start of the experiment. Next, segments of the continuous data were extracted, beginning when the reach windows illuminated, and ending before the actress initiated any movement (gaze or reach) towards one of the locations (see Supplemental Figure S5-1). During this period, the puppet had exited the screen. From this segment, we calculated the time (in milliseconds) during which X-Y eye gaze coordinates were directed towards the box containing the object, the other box, and actress (see Supplemental Figure S5-1). The length of this segment differed between particular video clips between 1-4 seconds. As such, we converted amount of time looking on each trial to proportion of looking. Specifically, proportion of looking to the actual location and the other location on a given trial was then calculated by dividing by the sum of the time spent looking at the actual location, the other location, and the person (following Schneider et al., 2014). Proportions were averaged across conditions to

produce an average proportion of looking for each condition type. Gaze locations of interest were defined by subset of total grid pixels (1366 x 768) that included the object of interest (left box/left window, right box/right window, and actress).

We were primarily concerned with determining whether participants showed different behavioral looking patterns during the true belief and false belief conditions, indicative of spontaneous theory of mind reasoning. To do so, we used multi-factor ANOVAs to compare the proportion of looking to the actual and other location between conditions (Schneider et al., 2014). Interactions were followed up with t-tests to compare means.

We also included a novel direct perception condition, where the boxes were clear and the location of the object was evident all at all times, to precisely match the false belief condition in all aspects (including lower-level motor movements) except the opacity of the boxes. Given the novelty of this condition, we had no strong a priori predictions regarding the looking patterns within the direct perception condition or in comparison to the other conditions. As such analysis of the direct perception condition was considered separately.

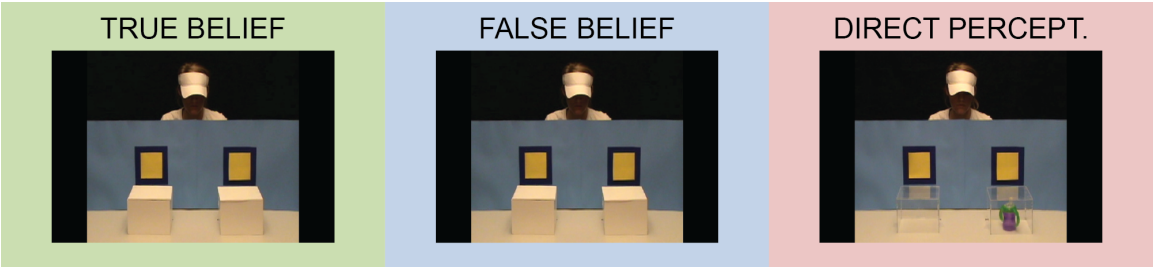

Figure S5-1. Screen shots of stimuli for each condition during time window used for eye gaze analysis.

Results

Our main analysis compared proportion of eye gaze at each of the two hiding locations in the true belief condition and the false belief condition (see Southgate et al., 2007; Schneider et al., 2014). An ANOVA on the average proportion of looking with the within-subjects repeated factors of Condition (true belief or false belief) and Location (object location or other location) and the between-subjects factor of False Belief Reach Type (reach for actual location or reach for other location) revealed a significant main effect of Location ($F(1,22) = 14.15$, $p < .005$) and a significant interaction between Location and Condition ($F(1,22) = 14.27$, $p < .005$). No other main effects or interactions were observed (all other p's > .06). Post-hoc paired samples t-tests revealed that participants spent more time looking to the actual location of the hidden object relative to the other location ($t(23) = 5.34$, $p < .00005$) in the true belief condition while they spent an equal amount of time looking at both locations in the false belief condition ($t(23) = 1.03$, $p = .32$) (see Supplemental Figure S5-2).

A review of the participant responses to our questionnaire revealed four subjects (out of 24) might have been explicitly reasoning about mental states during passive viewing. An analysis excluding these four subjects yielded largely the same results as the analysis with them. In particular, a comparison eye tracking data to the true belief and false belief conditions yielded a main effect of Location ($F(1,18) = 16.61$, $< .001$) and an interaction between Location and Condition ($F(1,18) = 8.24$, $p < .05$). Post hoc analysis showed that the interaction was driven by the fact that participants looked significantly longer at the actual location of the hidden object

relative to the other location in the true belief condition (t (19) = 5.16, p < .0001) but looked equally between conditions in the false belief condition (t (19) = 1.44, p > .16).

An analysis of proportion of looking in the direct perception condition revealed that participants looked significantly longer at the actual hiding location relative to the other location (t (23) = 4.66, p < .0005) (see Supplemental Figure S5-2). The same pattern of results was obtained after excluding those participants that may have been reasoning explicitly about mental states (t (19) = 4.36, p <. 0005). These results suggest that eye gaze data in the direct perception condition more closely matched that of the true belief condition compared to the false belief condition.

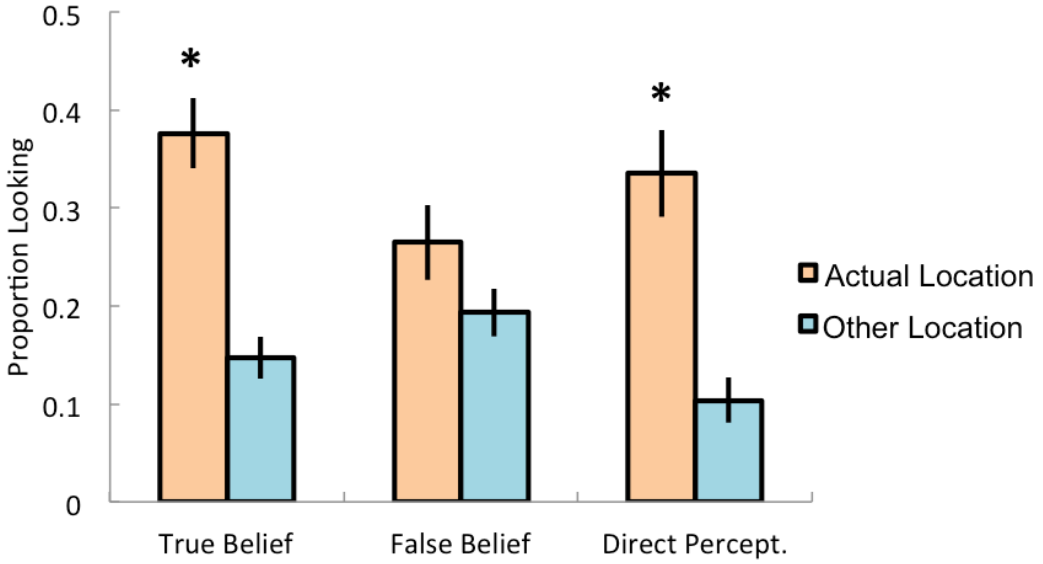

Figure S5-2. Eye gaze data for each condition. Asterisks (*) indicate statistically significant differences in looking between locations. Error bars represent -/+ 1 SEM.

Discussion

Our results show clear evidence of differential patterns of looking in anticipation of the actress reaching for an object. These patterns suggest that participants were clearly anticipating the reach of the actress in the true belief condition to the correct hiding location, spending significantly longer looking at the actual location where the item was hidden and where the actress would ultimately reach. A very similar pattern was seen in the direct perception condition when the object was located in a transparent container. In contrast to the direct perception and true belief conditions, participants looked towards the correct and incorrect location equally in the false belief condition. There were no explicit task instructions or cognitive demands in any of the conditions, making it easy for participants to track where the object actually was at all times. There were no low level or conceptual differences in the actual portion of the video for which the analyzed eye-gaze data corresponds (beyond box opacity-see Supplemental Figure S5-1). That is, in all conditions, the actress was facing forward, the puppet was not on the screen, and the object was in one of two boxes. However, only in the false belief condition did the knowledge of the actress about where the object was hidden conflict with its actual location. Looking patterns in the false belief condition suggested that expectations

regarding where the actress would reach were certainly different and may have been conflicted compared to the other conditions. As such, these results confirm that the different conditions of our stimuli, even if only passively viewed, likely evoked different expectations and these expectations correspond to whether or not the actress's knowledge about the location of the hidden object was consistent or inconsistent with the actual location.

Table S5-1. Questions asked to participants after participation in the eye tracking study (adapted from Schneider, Slaughter, Becker, & Dux, 2014)

Questions
1. What do you think the purpose of the experiment was?
2. What do you think this experiment was trying to study?
3. What were you trying to do while watching the videos? Did you have any particular goal or strategy?
4. When thinking about the two boxes on the table in the video, what box do you think you spent most time on, the left or right, from your perspective, not the actress/puppet?
5. What do you think was the story in the videos?
6. Did you notice that the actor sometimes had a true belief about the item location and sometimes a false belief about the item location when looking back at the boxes? • If participant is unsure of question: Did you notice that the actress was sometimes tricked about the item location when looking back and sometimes was not tricked about the item location when looking back at the boxes?) o If answer is yes: How did those beliefs become true or false/how was the actress tricked?