

How do we interpret questions? Simplified representations of knowledge guide humans' interpretation of information requests

Marie Aguirre, Mélanie Brun, Anne Reboul, Olivier Mascaro

▶ **To cite this version:**

Marie Aguirre, Mélanie Brun, Anne Reboul, Olivier Mascaro. How do we interpret questions? Simplified representations of knowledge guide humans' interpretation of information requests. Cognition, 2022, 218, 10.1016/j.cognition.2021.104954 . hal-03433052

HAL Id: hal-03433052
https://hal.science/hal-03433052

Submitted on 20 Nov 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

How do we interpret questions?

Simplified representations of knowledge guide humans' interpretation of information requests

Marie Aguirre[1*], Mélanie Brun[1], Anne Reboul[2], Olivier Mascaro[1]

[1] Université de Paris, INCC UMR 8002, CNRS, F-75006 Paris, France

[2] Laboratory of Cognitive Psychology, UMR 7290, CNRS and Aix-Marseille University, Marseille, France

Author note

The authors declare no conflict of interest.

Acknowledgements

We are grateful to all members of the Integrative Neuroscience and Cognition Center (INCC) and of the Laboratory on Language, Brain and Cognition (L2C2) for their help at all stages of this research, as well as to Justine Epinat-Duclos and Patrick Arthur Donaldson. We also express our gratitude towards preschools and all the families that participated in this project. This research was supported by a grant from the Fyssen foundation (IRIS: Infants' Representation of Informativeness in Social and non-social contexts) to OM and by two grants from the Agence Nationale pour la Recherche to OM (PragTICAL, ANR-14-ACHN-0020; FoundTrust, ANR-21-CE28-0017-01). This study contributes to the IdEx Université de Paris ANR-18-IDEX-0001.

* Corresponding author: Marie Aguirre, Université de Paris, CNRS, Integrative Neuroscience and Cognition Center, 75006, Paris, France. Contact: marie.aguirre77@gmail.com

Highlights:

- We test how mentalizing guides the interpretation of questions
- Children rely on tracking what people know (simple knowledge tracking)
- Children do not rely on tracking Socratic ignorance (knowledge of one's ignorance)
- Adults rely on simple knowledge tracking and on Socratic ignorance attributions
- Adults prioritize simple knowledge tracking over Socratic ignorance attributions

Abstract

This paper investigates the cognitive mechanisms supporting humans' interpretation of requests for information. Learners can only search for a piece of information if they know that they are ignorant about it. Thus, in principle, the interpretation of requests for information could be guided by representations of Socratic ignorance (tracking what people know that they do not know). Alternatively, the interpretation of requests for information could be simplified by relying primarily on simple knowledge tracking (i.e., merely tracking what people know). We judged these hypotheses by testing two-and-a-half-year-old toddlers (N = 18), five- to seven-year-old children (N = 72), and adults (N = 384). In our experiments, a speaker asked a question that could be disambiguated by tracking her state of knowledge. We manipulated the speakers' visuals to modulate the complexity of the ignorance representation required to disambiguate their questions. Toddlers showed no tendency to appeal to representations of Socratic ignorance when disambiguating questions (Pilot S1). Five- to seven-year-olds exhibited a similar pattern of results, and they performed better when information requests could be disambiguated using simple knowledge tracking (Studies 1a-1b). Adults used representations of Socratic ignorance to interpret questions, but were more confident when simple knowledge tracking was sufficient to disambiguate information requests (Studies 2-3). Moreover, adults disambiguated questions as if speakers could request information about things that they were ignorant of, even when speakers had no reason to know about their ignorance (Studies 3-4). Thus, the interpretation of requests for information rests primarily on simple knowledge tracking—and not on representations of Socratic ignorance—a heuristic that reduces processing costs.

Keywords: Theory of mind, questions, knowledge, pragmatics, cognitive development, naïve epistemology.

How do we interpret questions?

Simplified representations of knowledge guide humans' interpretation of information requests

1 Background

Humans have a remarkable disposition to ask questions and devote cognitive resources to determine what others want to learn. Even children request information by pointing, in infancy (Begus et al., 2014; Begus & Southgate, 2012; Kovács et al., 2014), and by asking appropriate questions, toddlerhood onwards (Chouinard, 2007; Kurkul & Corriveau, 2018; Ronfard et al., 2018). The capacity to formulate and interpret requests for information expands extraordinarily humans' ability to communicate cognitively useful information. This competence allows us to identify precisely others' specific informational needs, and thus, to address them. Significantly, for requests for information to play an efficient role in learning, they must be understood accurately. In this study, we investigated the nature and ontogeny of cognitive capacities supporting the interpretation of requests for information, with a particular focus on representations of ignorance. We studied the interpretation of interrogative sentences that are used to request information, referred to as "questions" (Bach & Harnish, 1979; Groenendijk & Stokhof, 1984; Karttunen, 1977; Searle, 1969).

1.1 Simple knowledge tracking and Socratic Ignorance

Humans are quite efficient in tracking what others can see, have experienced, or are aware of. This capacity develops very early during infancy (Kampis et al., 2015; Liszkowski et al., 2007; Luo & Baillargeon, 2007; Moll & Tomasello, 2006; O'Neill, 1996; Sodian et al., 2007), and often operates quickly and spontaneously (Beck et al., 2018; Furlanetto et al., 2016; O'Grady et al., 2020; Samson et al., 2010). From early childhood, humans rely on their ability to track what speakers know to disambiguate their meanings (Bohn & Köymen, 2018; Grosse

& Tomasello, 2012; Kampa & Papafragou, 2020; Khu et al., 2020; Mazzarella & Pouscoulous, 2020; Nadig & Sedivy, 2002; Nilsen & Graham, 2009; Nurmsoo & Bloom, 2008). Thus, humans have well-established and early developing capacities to track what someone saw, experienced or is aware of; we will refer to this capacity as "simple knowledge tracking".

Importantly, simple knowledge tracking is not sufficient to build a full-blown representation of information search. Indeed, learners will not look for a piece of information unless they detect that they lack it (e.g., if John believes his cell phone is at home, when it has actually been stolen, he will not search for it even though he does not know where it is, quite simply because he does not know that he is ignorant about his cell phone's location). Thus, building a full-blown representation of what triggers information search requires more than tracking what people do not know. It also requires determining what kind of information others are aware of lacking.

The detection of a lack of information is a basic component of information search (Bromberger, 1992; Loewenstein, 1994). Yet, monitoring the detection of a lack of information in others is far from trivial. For human adults, representing someone's awareness of lacking a piece of information can be achieved by tracking what they know that they do not know (henceforth, "Socratic ignorance", named as such after the Greek philosopher Socrates, who famously emphasized the importance of knowing what one is ignorant about). Representations of Socratic ignorance imply the capacity to attribute complex mental states about mental states; for example, representing "John knows that he does not know where his cell phone is." Thus, to represent Socratic ignorance, one needs to attribute "second-order" mental states, i.e., mental states about mental states about reality (Perner & Wimmer, 1985).

The representation of information search differs depending on whether it is achieved with simple knowledge tracking or with Socratic ignorance attribution mechanisms. To illustrate, imagine that John has left his laptop on his kitchen table and his cell phone inside the

drawer of the same table. Later on, while John is absent, his friend Melissa stores both his laptop and his cell phone in John's room, unbeknownst to him. Upon returning to the kitchen, John can see that his laptop has disappeared (it is no longer on the table); he does not see that his cell phone has moved (since he left it inside a drawer). John asks Melissa: "*Where is it?*". If Melissa relies on simple knowledge tracking to interpret John's question, she will assume that John is equally likely to refer to his laptop or to his cell phone (since he is ignorant about the location of both). In contrast, if Melissa relies on representations of Socratic ignorance to interpret John's question, she will assume that John is referring specifically to his laptop (since John knows only about his ignorance about his laptop's location).

Thus, in principle, humans could use either simple knowledge tracking or representations of Socratic ignorance to interpret requests for information. These two mechanisms differ in complexity and accuracy. Simple knowledge tracking is arguably less complex than representations of Socratic ignorance. Yet, it can only support simplified representations of information search (it does not take into account people's knowledge of their ignorance). The monitoring of Socratic ignorance is more complex (it involves embedded representations of knowledge about someone's ignorance); yet, it is necessary to build a full-blown representation of information search. We tested which of these two representations of knowledge states guides the interpretation of requests for information, capitalizing on adults' and children's sensitivity to what people ignore when interpreting questions (Brown-Schmidt et al., 2008; Brown-Schmidt & Fraundorf, 2015; Grosse & Tomasello, 2012; Nurmsoo & Bloom, 2008). We outlined three hypotheses about the processes supporting the interpretation of requests for information, each of which makes distinct developmental predictions.

1.2 Hypothesis 1. Developmental continuity—Early use of Socratic ignorance attributions

Complex recursive reasoning about mental states is often involved in social interactions (Grueneisen et al., 2015; Siposova et al., 2021). Thus, the first hypothesis is that humans appeal primarily to early developing representations of Socratic ignorance when interpreting information requests. The capacity to form verbal representations of Socratic ignorance appears to develop during late childhood (Miller, 2009; Perner & Wimmer, 1985; Sullivan et al., 1994). Yet, a few studies indicate that children might be able to manipulate complex second-order representations of representations at a relatively young age. For instance, four-year-old children recognize the involutive nature of falsity ascriptions — i.e., inferring « p » from « It is not true that it is not true that p » (Mascaro & Morin, 2015).

Moreover, the interpretation of requests for information might very well rest on implicit representations of Socratic ignorance, which could develop quite early. The capacity to represent what other people have seen or experienced emerges well before young children can manipulate verbal representations of knowledge and ignorance. For instance, children can answer questions about other individuals' knowledge from three years of age onwards (Pratt & Bryant, 1990). Yet, humans' sensitivity to what others have seen or experienced is observed at a much earlier age, during infancy, when children's capacities are tested implicitly (Kampis et al., 2015; Liszkowski et al., 2007; Luo & Baillargeon, 2007; O'Neill, 1996; Phillips et al., 2020). Such a sensitivity to what people have seen or experienced guides the interpretation of communicated information from toddlerhood onwards (e.g., Carpenter et al., 2002; Grosse et al., 2010; Grosse & Tomasello, 2012; Liebal et al., 2009; Nurmsoo & Bloom, 2008; for a review see Mazzarella & Pouscoulous, 2020). In principle, a similar discrepancy between verbally accessible representations and implicit capacities might be observed for representations of Socratic ignorance. If this were the case, young children would be able to manipulate implicit representations of Socratic ignorance well before they can talk about them, and might use them to interpret requests for information (Hypothesis 1). Validating this hypothesis would suggest

that children, who answer questions from infancy onwards, can form representations of second-order mental states much earlier than previously thought.

1.3 Hypothesis 2. Developmental discontinuity—From simple knowledge tracking to attributions of Socratic ignorance

A second hypothesis is that during ontogeny children start by using simple knowledge tracking to interpret requests for information, and later on shift to using attributions of Socratic ignorance when they become able to manipulate them explicitly. This hypothesis predicts that children's use of Socratic ignorance to interpret questions should appear along with their capacity to manipulate explicit verbal representations of second-order mental states, between five and seven years of age (Miller, 2009; Perner & Wimmer, 1985; Sullivan et al., 1994). Validating this hypothesis would reveal that the way humans interpret questions changes dramatically during development, and involves simple knowledge tracking, initially, and later on, attributions of Socratic ignorance.

1.4 Hypothesis 3. Developmental continuity—Simple knowledge tracking

The third hypothesis is that the interpretation of information requests rests primarily on simple knowledge tracking, rather than on attributions of Socratic ignorance, both in children and adults. In order to request a piece of information that one lacks, one needs to detect that one is ignorant about that piece of information. Thus, attributions of Socratic ignorance are critical to building a full-blown representation of others' information search. However, in many cases, simple knowledge tracking is sufficient for interpreting information requests. Several factors may contribute to the primacy of simple knowledge tracking in the interpretation of questions (for more details, see the general discussion). Tracking Socratic ignorance is costly and difficult (e.g., Arslan et al., 2017). Simply put, representing "A knows that A does not

know p" is more complex than representing "A does not know p." Moreover, it is not certain that the mechanisms supporting the fast online tracking of knowledge can represent complex mental states embedded within mental states, such as Socratic ignorance. Perhaps some (or all) of these mechanisms can only perform simple knowledge tracking (e.g., Apperly & Butterfill, 2009; Westra & Nagel, 2021). In addition, when people request information, they convey a very special presumption of competence. They imply that they have sufficient knowledge about their ignorance to identify what kind of information might be useful for them.

Thus, the interpretation of requests for information can be simplified by using simple knowledge tracking rather than representing Socratic ignorance. This heuristic should be efficient because it reduces the cognitive costs associated with processing questions. Furthermore, it should result only in infrequent mistakes that can be clarified in conversation, and that are mostly harmless; if a speaker requests for a piece of information, and the listener replies by providing the speaker with a relevant piece of information that the speaker lacks (yet, was not aware of not knowing), the speaker still learns something useful. Thus, there are reasons to believe that the interpretation of questions may rest primarily on simple knowledge tracking. If this hypothesis is correct, even populations that can represent second-order mental states might prioritize simple knowledge tracking over representations of Socratic ignorance to interpret requests for information. Validating this hypothesis would reveal that humans appeal to a simplification heuristic when interpreting questions.

To summarize, we outlined three possible hypotheses about the interpretation of information requests. Since learners can only request a piece of information when they realize that that they lack it, the interpretation of requests for information may rely primarily on representations of Socratic ignorance. These representations could develop early and operate throughout the learner's lifespan (Hypothesis 1: Developmental continuity—early use of Socratic ignorance attributions), or they may emerge late, along with the capacity to reason

explicitly about second-order mental states (Hypothesis 2: Developmental discontinuity—from simple knowledge tracking to attributions of Socratic ignorance). Alternatively, the interpretation of requests for information may rest primarily on simple knowledge tracking, a heuristic that reduces processing costs (Hypothesis 3: Developmental continuity—simple knowledge tracking).

1.5 Operationalization principle

First, we tested two-and-a-half-year-old toddlers in a live interactive paradigm testing their sensitivity to Socratic ignorance (Pilot S1, reported in the supplementary materials). The results of this pilot study supported the null hypothesis: Toddlers showed no tendency to appeal to representations of Socratic ignorance when disambiguating questions. Importantly, this pilot study did not include a condition measuring toddlers' reliance on simple knowledge tracking when interpreting information requests. Subsequently, this pilot Study did not directly compare the respective roles of simple knowledge tracking and of attributions of Socratic ignorance in toddlers' interpretation of questions.

In subsequent studies, we compared systematically humans' reliance on simple knowledge tracking and on Socratic ignorance attributions when interpreting questions by testing children (Studies 1a-1b) and adults (Studies 2-4). In Studies 1a and 1b, we assessed whether the use of Socratic ignorance to interpret questions emerges along with changes in the capacity to manipulate explicit representations of second-order mental states. Thus, we tested five- to seven-year-old participants, i.e., over an age span during which the capacity to manipulate explicit representations of second-order mental states typically increases (Miller, 2009). We relied on second-order false belief tasks to assess our participants' capacity to manipulate explicit representations of second-order mental states (Perner & Wimmer, 1985; Sullivan et al., 1994).

To judge our hypotheses, we used scenarios in which adult speakers asked questions about the location of an object using a label. In all question tests, the label could refer to one of two different objects. This ambiguity could be resolved by tracking the speakers' state of knowledge. In the first-order question test, the speakers were ignorant about the location of only one of the two objects. Thus, it was possible to disambiguate what the speakers wanted to learn by using simple knowledge tracking. In the second-order question test, the speakers were ignorant about the location of both the objects; notably, the speakers knew about their ignorance of the location of only one of the two objects. Thus, it was possible to disambiguate what the speakers wanted to learn, by tracking what they knew that they did not know, but not merely by tracking what they did not know. In both the first-order and second-order question tests, we assessed participants' interpretations of the ambiguous information request.

In Study 1a, we tested five- to seven-year-olds on a first-order question test in which they could determine the meaning of a request for information by using simple knowledge tracking. Thus, Study 1a served to validate our stimuli and our data analysis procedure, and to estimate the sample sizes required for testing children's sensitivity to Socratic ignorance in Study 1b (as a result, Study 1a was tested before Study 1b, and is reported first). In Study 1b, we tested five- and seven-year-old children on the second-order question test and second-order false belief tasks. In Studies 1a-1b, we collected both eye-tracking data and answers to explicit questions because both of these measures are suitable for five- to seven-year-old children. Had we found positive evidence for five-year-olds' use of Socratic ignorance in Studies 1a-1b, our eye-tracking paradigm would have allowed us to test much younger children to determine how early the capacity to track Socratic ignorance develops. Moreover, gaze behaviors sometimes reveal abilities at an earlier age than explicit answers (e.g., Bergelson & Swingley, 2012; Dautriche et al., 2021; Köder & Falkum, 2020). Thus, collecting both eye-tracking data and

explicit answers allowed us to probe whether there was a dissociation, or some consistency, between children's explicit choices and their gaze behaviors.

Studies 1a and 1b allow us to evaluate our three hypotheses. If, from a young age, children primarily use attributions of Socratic ignorance to interpret questions, then all groups will succeed in the second-order question test of Study 1b, even five-year-old children and children who fail at explicit second-order false belief tasks (Hypothesis 1). We will observe a different pattern if children's reliance on attributions of Socratic ignorance to interpret questions emerges along with explicit verbal representations of second-order mental states. In that case, performance on the second-order question test will increase between five and seven years of age, and it will be positively related to performance in second-order false belief tasks (Hypothesis 2). If the interpretation of questions rests primarily on simple knowledge tracking, then children's performance will be better in the first-order test than in the second-order test (Hypothesis 3).

Data, stimuli samples, and analysis scripts of all Studies are accessible on an open repository (URL : https://osf.io/dneqm/?view_only=d3b3fcfa894b49d99e18b50801d337fb).

1.6 Ethics

This project was approved by an independent ethical committee for biomedical research (CPP Sud-Est II, IRB: 00009118). All adult participants and the parents of all toddler and child participants provided written informed consent, prior to their inclusion in the study.

2 Study 1a

2.1 Methods

2.1.1 Participants

We tested sixteen five- to seven-year-olds (10 girls, 6 boys; M_{age} = 77.9 months; *SD* = 12.2; age range: 61–95 months). The participants were all native French speakers recruited from a large French city (Lyon). Children were recruited by sending letters to a randomly selected sample of children born in the area. A priori, we planned to exclude participants for the following reasons: refusal to complete the whole procedure, technical failure, low-quality data (more than two test sequences with 50% or more of the eye-tracking data missing), and parental interference. In Study 1a, no participant was excluded from the analysis. The sample size of Study 1a was set a priori to be large enough while limiting recruitment efforts.

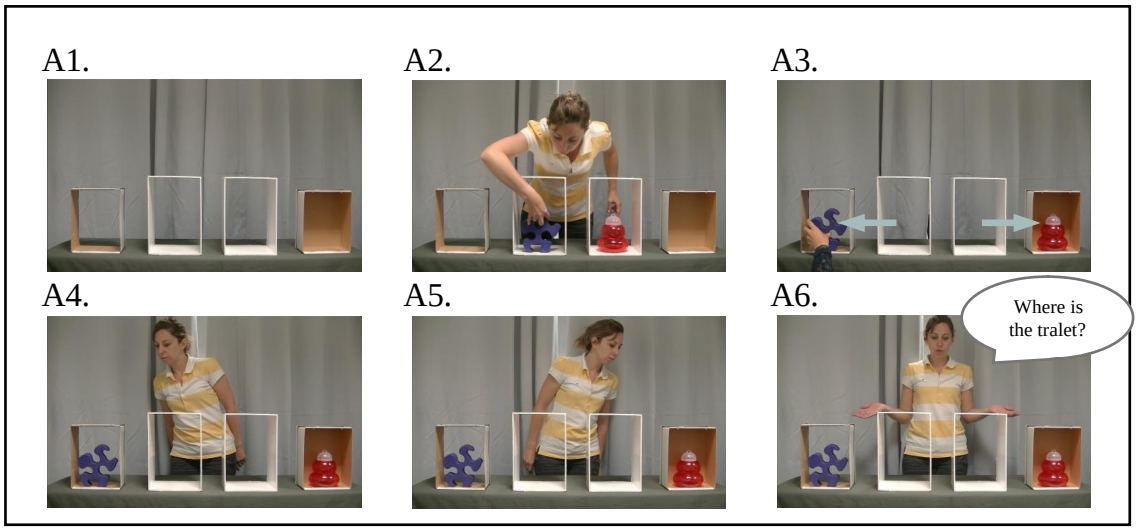
2.1.2 Materials and Procedure

Eye-tracking Experiment. The study started with an eye-tracking experiment that took place in a soundproof booth. The participants sat approximately 60 cm away from the eye tracker's monitor on which the stimuli were presented (Tobii Pro Spectrum 150, sampling frequency: 60 Hz, screen diagonal: 23.8", resolution: 1920×1080 pixels). For stimuli presentation and data collection, we used Psychopy v.3.0.4, (Peirce et al., 2019) associated with Python v.2.7, and Tobii Pro SDK package v.1.7. We used a five-point calibration method, repeated until it was complete. The participants typically required only one calibration.

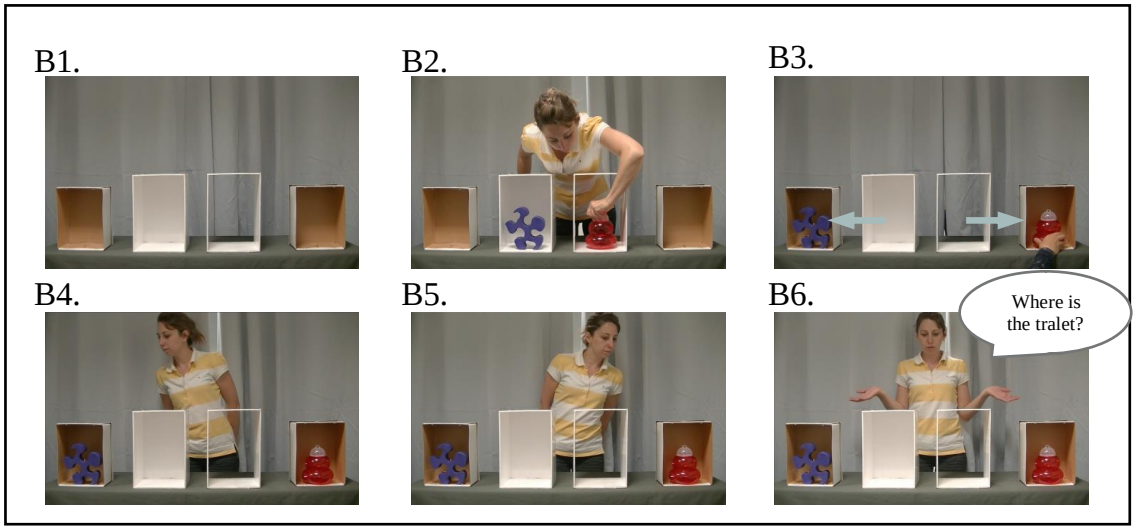
Figure 1.

Critical Events of Studies 1a and 1b.

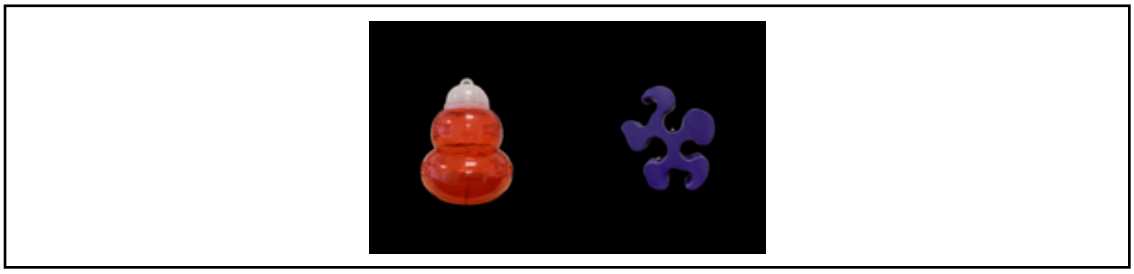
A. First-order test (Study 1a)



B. Second-order test (Study 1b)



C. Test phase



Note: Panels A (A1–6): Photographs from the familiarization of the first-order test condition (Study 1a). Panels B (B1–6): Photographs from the familiarization of the second-order condition (Study 1b). Panel C: Photograph from the two-alternative forced choice test.

The eye-tracking experiment was initiated after the calibration phase. First, the participants saw a familiarization video that lasted 50 seconds (see Video S1 in the Supplementary Materials), twice. In this video, there were four boxes made of opaque cardboard, placed in a row on a table: two larger central boxes in the central part of the table, and two peripheral smaller boxes located next to the edges of the table. The boxes had no frontside, so that the participants could see their content at all times. One of the peripheral boxes had an opaque backside; thus, it was impossible for anyone facing the participant across the table to see its contents (see Figure S3 panel A in the Supplementary Materials). The other three boxes had no backsides. At the beginning of the video, all boxes were empty (see Figure 1, panel A1). Next, a female actor entered the scene through an opening at the center of the opaque curtains located in the background. She carried two unfamiliar objects: a purple wooden structure ornamented with silver balls and a transparent, round, red plastic structure with a white top. She placed the objects one after the other in each of the two central boxes (see Figure 1, panel A2). Following this, the female actor returned behind the curtains. While she was away, a hand appeared from the bottom of the screen, and displaced each of the two unfamiliar objects one by one, each time from the central box where the object was initially located to the outer box located on the same side (see Figure 1, panel A3). When the female actor returned through the opening in the curtains, she pretended to search for an object (first, looking toward the center of the table, second, looking across the whole table from one side to another, and third, looking back toward the center again). From her perspective, she could not see the object placed in the box with an opaque backside (we call this object the "target" when reporting the analysis

and results of Study 1a), whereas she could see the other object (see Figure 1, panels A4 and A5). Next, she flipped the palms of her hands upward and out to the side, and she asked for the location of one of the objects, using a novel label (the nonsense word "tralet"): She looked toward the center of the table, and said, "*Where is the tralet?… Where did the tralet go?… Where is the tralet?*" (see Figure 1, panel A6).

After watching the familiarization movie, the participants were enrolled in the test phase, which consisted of four test sequences using a two-alternative forced-choice (2AFC) task. The participants saw the two unfamiliar objects from the familiarization videos, each of them on one side of the screen, on a black background (see Figure 1, panel C). During each of the test sequences, a voice-over invited the participant to look at the object that was referred to by the novel label by asking a prompt question (e.g., "*Did you see the tralet?*") followed by five seconds of silence. After this, the subsequent test sequence began. The sides where the objects were located were switched between test sequences. There were four consecutive test sequences, resulting in four measures (one after each prompt question). The prompt questions differed from one test sequence to the next, and were as follows, "*Where is the tralet?*" (test sequences 1 and 3), and "*Did you see the tralet?*" (test sequences 2 and 4), respectively.

The same label ("tralet") was always used to refer to the object that the female actor was searching for. During the familiarization phase, we counterbalanced the following factors across participants: the side of each unfamiliar object (right or left), the side of the box with the opaque backside (right or left), the side toward which the female actor looked first when searching for the object across the table (right or left), and the identity of the target (purple or red object). During the test phase, we counterbalanced within subjects the side of the screen on which each unfamiliar object appeared across test sequences (right or left).

Explicit Identification Test. After completing the eye-tracking experiment, the participants were enrolled in an explicit identification test outside the soundproof booth. The

experimenter showed one picture of each of the unfamiliar objects, side by side on a single sheet of paper. She asked the participant to explicitly identify the target by saying, "*Which one is the tralet?*" The side of the sheet (left/right) occupied by the picture representing the object that was in the box with an opaque backside during the familiarization phase was counterbalanced across participants.

Standard Second-order False Belief Tasks. The child participants sat in front of the experimenter, across a child-sized table, and were enrolled in two classic standard second-order false belief tasks while being filmed with a camera (temporal resolution = 30 frames per second). There were two tasks: one about a birthday puppy and one about a chocolate bar (adapted from Sullivan et al., 1994; and illustrated with vignettes from Avik Kumar Maitra, see Arslan et al., 2020). In the birthday puppy task, a mother deliberately misinforms her son about what he will receive for his birthday, so as to surprise him. Yet, the child actually discovers the true birthday present, unbeknownst to his mother. Later, the child's grandmother asks the mother whether the child knows what he is getting for his birthday (second-order knowledge question), and then what the child thinks he is getting (second-order belief question). In the chocolate bar task, a sister displaces her brother's chocolate bar, to hide it from him. Unbeknownst to the sister, the brother sees her displacing the chocolate bar in the new location. Later, the participants were asked whether the sister knows that her brother knows where the chocolate bar is (second-order knowledge question), and where the sister thinks that her brother believes the chocolate bar is (second-order belief question). After each of the second-order knowledge and second-order belief questions, the participants were asked to justify their answers (follow-up justification questions). The scripts for each of these tasks are detailed in the Supplementary Materials. The order of presentation of the two second-order false belief tasks (chocolate bar and birthday puppy) was counterbalanced across participants.

2.1.3 Pre-processing and Coding

Eye-tracking Experiment. We pre-processed the eye-tracking data (v. 4.0.3; R Core Team, 2020) using the package eyetrackingR (v. 0.1.8; Dink & Ferguson, 2015). We analyzed the eye-tracking data collected in the test phase during the silence period following the prompt questions (e.g., "*Did you see the tralet?*"). We restricted our analysis to a predefined time window classically used in two-alternative forced-choice tasks, from 367 ms to 2000 ms after the onset of the target label ("tralet"). Gaze behaviors occurring outside this time window are typically assumed to be unrelated to the processing of the target label (Swingley, 2007; Swingley & Aslin, 2000).

To analyze the eye-tracking data, we divided the screen centrally into two sides of 960×1080 pixels (i.e., the left and right sides of the entire screen). For each participant, we computed the proportion of looking toward the target for each 20 ms time interval by summing up the time spent looking at the side of the target object and dividing it by the total time spent looking at the entire screen over that time bin. Following this, for each participant, we computed the average of these proportions, across all test sequences for each time bin, and then, across all time bins. We excluded the data from test sequences, in which we missed more than 50% of the data (2 test sequences out of 64). In total, each participant contributed an average of 3.81 (SD = 0.54) of 4 test sequences.

Explicit Identification Test. For the explicit identification test, the participants received a score of 1 if they appropriately answered by selecting the target object, and a score of 0 otherwise.

Standard Second-order False Belief Tasks. For the standard false belief tasks, the participants received a score of 1 for each correct answer on a test question (second-order knowledge and second-order belief questions), and for each correct answer on the corresponding follow-up justification question, thus resulting in a score ranging from 0 to 4 for

both second-order knowledge questions and second-order false belief questions (see the Supplementary Materials for more details).

2.1.4 Data Analysis

All statistical analyses reported in this paper were two-tailed. Unless specified otherwise, they were performed using R (v. 4.0.3; R Core Team, 2020) with the following packages: lme4 (v. 1.1.26; Bates et al., 2015), lmerTest (v. 3.1.3; Kuznetsova et al., 2017), logistf (v. 1.24; Heinze et al., 2020) and rcompanion (v. 2.3.27; Mangiafico, 2021). In all studies of this paper, the confidence intervals reported for binomial tests are obtained by a procedure first given in Clopper and Pearson (1934). In Study 1a, to better approximate a normal distribution, we transformed the proportion of looks toward the target prior to data analysis using an angular transformation (arcsin of squared root data). For ease of reading, we reported untransformed data in the text and figures. Where applicable, we also reported non-parametric statistics of untransformed eye-tracking data.

We assessed the effect of the factors in the following manner. For the eye-tracking data, we ran linear models with the transformed proportion of looks toward the target as the dependent variable. For the data from the explicit identification test, we ran generalized linear models (binomial distribution and logit link) with the binary success score as the dependent variable. In case of complete or quasi-complete separation of the data, we used logistic regression models using Firth's bias reduction method. Age was entered in months (mean-centered) when it was included in the statistical model.

2.2 Results

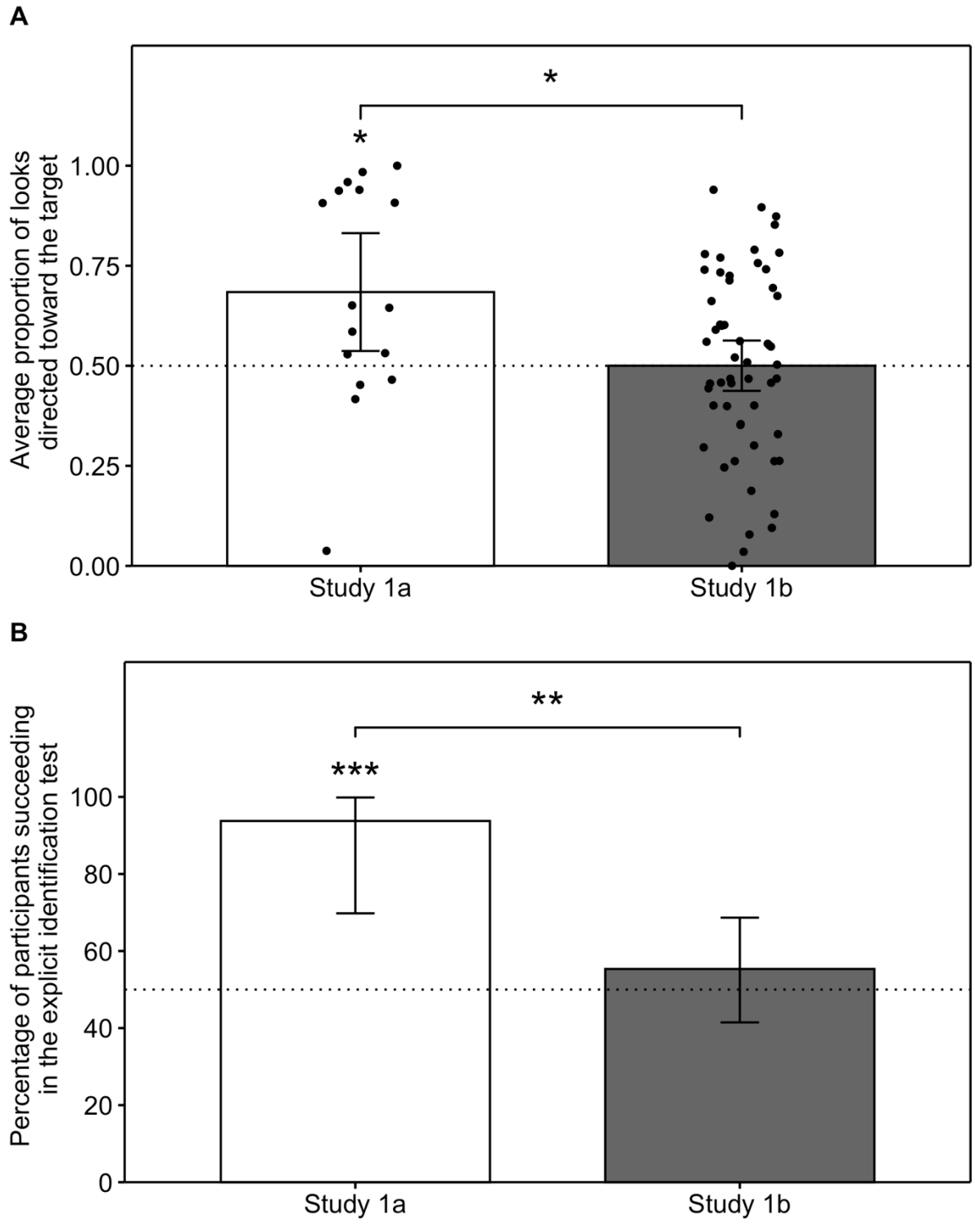
We assessed the respective effects of the variables on participants' performance in the eye-tracking test and in the explicit identification test. Since age, second-order knowledge scores, and second-order false belief scores were all positively correlated (M_{rho} = .60; range = .45 - .81), we assessed their contribution separately to avoid collinearity issues. Thus, we

fitted the following series of models: (1) the age model (with the fixed effect of Age), (2) the ignorance model (with the fixed effect of second-order knowledge score), and (3) the false belief model (with the fixed effect of second-order false belief scores). None of the three models revealed any main effect for the eye-tracking experiment or for the explicit identification test (see Table S1 and Table S2 in the Supplemental Materials for details). Thus, there was no evidence for an effect of age or scores on second-order false belief tasks on the participants' interpretation of questions in Study 1a.

Following this, we compared the performance of the participants with what was predicted by chance. The descriptive statistics are reported in Figure 2 (panel A : eye-tracking experiment; panel B: explicit identification test). In Study 1a, the participants' performance was significantly higher than what was predicted by chance in the eye-tracking experiment (average proportion of looks toward the target: $M = 0.68$, $SD = 0.28$; $t(15) = 2.58$, $p = .021$, $d = .65$, one-sample t-test; $Z = 110$, $p = .029$, $r = .62$, Wilcoxon signed-rank test on untransformed data) and in the explicit identification test (15 successes out of 16; $p < .001$, $g = .44$, binomial test).

Figure 2.

Results of Studies 1a and 1b; Panel A: Average Proportion of Looks Directed Toward the Target Object; Panel B: Percentage of Participants Successful in the Explicit Identification Test.



Note: The dotted lines represent the level of performance predicted by chance (i.e., 0.5 in panel A and 50% in panel B). In Study 1a, the "target" was the object that the actress could not see when she asked about the location of the "tralet" ; in Study 2b, the "target" was the object initially placed in the central box with no backside, i.e., the object whose former location (now empty) was visible for the actress when she asked about the location of the "tralet". Error bars represent 95% CI. Panel A: Comparisons against chance by one-sample Wilcoxon tests and Comparison between studies by Mann-Whitney U test. Panel B: Comparisons against chance by binomial tests and comparison between studies by Fisher's exact test.

*: $p < .05$, **: $p < .01$, ***: $p < .001$.

2.3 Discussion

In Study 1a, children succeeded in appropriately identifying the referent of the novel label, both in the implicit and explicit identification tests. Thus, children tracked what the adult knew based on what she could and could not see, and used this information to interpret her questions. These results validate our stimuli and data processing procedures. In particular, they revealed that when watching the familiarization videos, the participants spontaneously used information about the female actor's knowledge to interpret her requests for information. In Study 1b, we built upon these results to investigate the role of representations of Socratic ignorance in the interpretation of questions.

3 Study 1b

3.1 Methods

3.1.1 Participants

We computed the sample size required for Study 1b using G*power (v. 3.1; Faul et al., 2007). These analyses revealed that assuming effect sizes identical to those observed in Study

1a, a sample size of twenty-eight participants per group was sufficient to achieve a power of .90 (α = .05) for comparisons against chance (see Table S3 in the Supplementary Materials). Thus, we tested twenty-eight participants for each age group, i.e., five-year-old children (12 girls, 16 boys; M_{age} = 64.5 months; *SD* = 3.58; age range: 60–71 months) and seven-year-old children (15 girls, 13 boys; M_{age} = 89.2 months; *SD* = 4.09; age range: 84–95 months). The exclusion criteria were the same as in Study 1a. We excluded seven participants for the following reasons: refusal to complete the whole procedure (1), technical failure (5), low-quality data (1). None of the children who participated in Study 1b had participated in Study 1a.

3.1.2 Materials and Procedure

Study 1b followed the same procedure as Study 1a, except for changes in familiarization movies. In the familiarization movies of Study 1b (see video S2 in the Supplementary Materials), only one of the central boxes had no backside. The three other boxes had opaque backsides (the second central box, and the two peripheral boxes, see Figure 1 panel B1). Thus, when the female actor stood behind the table, she could only see inside the box with no backside. After placing the two unfamiliar objects inside the central boxes, the female actor left the scene, and the objects were displaced, as in Study 1a (Figure 1 panels B2 and B3). Thus, when the female actor returned after the displacement of the unfamiliar objects, she was ignorant of the location of the two unfamiliar objects (since she could not see them, see Figure S3 panel B in the Supplementary Materials). Notably, she could see that the object initially placed in the central box with no backside was no longer there, thus making her knowledgeable about her ignorance of this object's location (we call this object the "target" while providing details regarding the analyses planned for Study 1b). Conversely, the female actor could not see that the object that she placed initially in the central box with a backside was no longer there, thus making her unaware of her ignorance of the object's location (Figure 1 panels B4, B5, and B6). In Study 1b, we counterbalanced the same factors as in Study 1a, except that

instead of counterbalancing the side of the box with no backside, we counterbalanced the side of the box with an opaque backside across participants.

3.1.3 Data Analysis

The data of Study 1b were pre-processed and coded as in Study 1a. In the eye-tracking experiment, we excluded the data from test sequences for which we missed more than 50% of the data (26 test sequences out of 224). In total, each participant contributed an average of 3.57 (*SD* = 0.74) out of four test sequences in the five-year-old children's group, 3.79 (*SD* = 0.57) out of four test sequences in the seven-year-old children's group.

We used the same data analysis procedure and software as in Study 1a, with the following additions: When analyzing the eye-tracking data, we used likelihood ratio tests (LRTs) to compare the models. Due to the complete separation of data, when analyzing performance in the explicit identification test, we fitted logistic regression models using Firth's bias reduction method, and compared models using penalized LRTs.

Moreover, for the null results of the main interest, we conducted Bayesian tests with Jasp (v. 0.14.1; JASP Team, 2020), with a Cauchy Prior Distribution set to the default value (.707). When conducting the Bayesian Wilcoxon signed-rank test, we used a data algorithm with five chains of 1000 iterations. We report the Bayes factors expressing support for the null hypothesis over the alternative hypothesis (BF_{01}). Any value of BF_{01} larger than 3 is typically interpreted as meaningful evidence for the null hypothesis.

3.2 Results

First, we analyzed the results of Study 1b. We fitted the following series of models: (1) the age model (with the fixed effect of age), (2) the ignorance model (with the fixed effect of second-order knowledge score), and (3) the false belief model (with the fixed effect of second-order false belief score). None of these models revealed any main effect either for the eye-

tracking experiment, or for the explicit identification test (see Table S1 and Table S2 in the Supplemental Materials for details). Thus, there was no evidence for an effect of age or scores on second-order false belief tasks on the participants' interpretation of questions in Study 1b.

As shown in Figure 2, in Study 1b, participants' performance did not differ significantly from what was predicted by chance, either in the eye-tracking experiment (proportion of looks toward the target: $M = 0.50$, $SD = 0.24$, $t(55) = -0.17$, $p = .86$, $d = -.02$, one-sample t-test; $Z = 830$, $p = .80$, $r = .04$, Wilcoxon signed-rank test on untransformed data), or in the explicit identification test (31 successes out of 56; $p = .50$, $g = .05$, binomial test). Complementary Bayesian analyses of Study 1b's results provided evidence for the null hypothesis in the eye-tracking experiment ($BF_{01} = 6.77$, error % < .001, Bayesian one-Sample t-tests; $BF_{01} = 6.85$, Bayesian Wilcoxon signed-rank test on untransformed data), and in the explicit identification test ($BF_{01} = 4.41$, Bayesian binomial test).

In a subsequent analysis, we wanted to determine whether children with established capacities to represent second-order mental states would still fail in the second-order question test. Thus, we focused on the performance of the participants whose scores on the explicit second-order false belief tasks were high (i.e., who reached a cumulative score of 7 or more out of 8, for their answers on the second-order knowledge and second-order belief questions; $n = 17$; $M_{age} = 85.2$ months; $SD = 11.0$; age range: 64–95 months). The performance of participants with high scores on second-order false belief tasks did not differ significantly from what was predicted by chance, either in the eye-tracking experiment (proportion of looks toward the target: $M = 0.47$, $SD = 0.24$; $t(16) = -0.52$, $p = .61$, $d = -.13$, one-sample t-test; $Z = 66$, $p = .64$, $r = -.14$, Wilcoxon signed-rank test on untransformed data; $BF_{01} = 3.56$, error % = .006, Bayesian one-sample t-test on transformed data; $BF_{01} = 3.43$, Bayesian Wilcoxon signed-rank test on untransformed data), or in the explicit identification test (9 successes out of 17, $p = 1$, $g = .03$, binomial test; $BF_{01} = 3.34$, Bayesian binomial test). Thus, even the

participants with a high score on the second-order false belief tasks showed no evidence of relying on the attribution of Socratic ignorance to interpret questions.

Finally, we assessed whether participants performed better when information requests could be disambiguated using simple knowledge tracking (Study 1a), than when representations of Socratic ignorance were required (Study 1b). We pooled the data from Studies 1a and 1b, and ran omnibus analyses to assess the respective effects of the variables on the participants' performance in the eye-tracking and explicit identification tests. We fitted the following series of models: (1) a test model, which included only the fixed effect of the studies (1a vs. 1b); (2) the age model (with the fixed effects of study, age, and their interaction); (3) the ignorance model (with the fixed effects of study, second-order knowledge score, and their interaction); and (4) the false belief model (with the fixed effects of study, second-order false belief scores, and their interaction).

The goodness of fit of the age, ignorance, and false belief models did not differ significantly from the goodness of fit of the test model, either for the eye-tracking test or for the explicit identification test. Thus, we retained the test model as the final model. The latter revealed a main effect of study, with hits more likely to occur in Study 1a than in Study 1b, both in the eye-tracking experiment ($F(1,70) = 8.31$, $p = .0052$, and in the explicit identification test ($\beta = -2.12$, $SE = 0.92$, *Wald's* $\chi^2 = -8.56$, $p = .003$). We also confirmed the effect of the study on children's behaviors in the eye-tracking experiment in a cluster-mass test analysis, which made no a priori hypothesis on the time window of the effect (see the Supplementary Materials).

3.3 Discussion

Studies 1a-b revealed a consistent pattern of results across measurements (eye-tracking and explicit questions). Children participants successfully interpreted questions when simple

knowledge tracking was sufficient to disambiguate them (Study 1a). Conversely, children showed no evidence for using representations of Socratic ignorance to disambiguate the meaning of requests for information, with data supporting the null hypothesis (Study 1b). Moreover, success in tasks requiring participants' use of Socratic ignorance to interpret questions was unrelated to participants' capacity to answer explicit questions about second-order mental states. In fact, even children who were proficient in manipulating representations of second-order mental states in second-order false belief tasks did not seem to use representations of Socratic ignorance to interpret questions.

In addition, participants performed better in Study 1a than in Study 1b, and thus were much more proficient at using simple knowledge tracking than at using representations of Socratic ignorance when interpreting requests for information. These results suggest that even when children possess the capacity to manipulate explicit representations of second-order mental states (such as representations of Socratic ignorance), their interpretation of requests for information relies primarily on simple knowledge tracking (Hypothesis 3). In Study 2, we tested whether this phenomenon remains valid in adulthood. If this is the case, adults will be less confident in their interpretation of a question's meaning when accessing it requires the use of representations of Socratic ignorance, instead of simple knowledge tracking. In Studies 1a-b, there was no dissociation between participants' performance on the explicit identification test, and in the eye-tracking task. Thus, we used only explicit identification tests in subsequent studies.

4 Study 2

4.1 Methods

4.1.1 Participants

In Study 2, two groups of sixty-four adult French-speaking participants were randomly assigned to one of two conditions (first-order condition: 31 females, 31 males, 2 other; M_{age} = 26.0 years; *SD* = 4.83; age range: 18–35 years, second-order condition: 29 females, 35 males; M_{age} = 25.1 years; *SD* = 4.64; age range: 18–35 years). The participants were recruited using the online platform Prolific (https://www.prolific.co). We chose to test adults online (i) because of the COVID pandemic, which made it impossible to host participants in our laboratory, and (ii) because online testing makes it possible to recruit large samples of participants. In order to be included, the participants needed to fulfill the following criteria: (i) be between 18 and 35 years of age, (ii) speak French as their first language, (iii) be of French nationality, and (iv) possess a tablet or regular computer device. We had intended to exclude participants for the following reasons: refusal to complete the entire procedure and failure on an attention check. None of the participants were excluded from the analysis in Study 2. The sample sizes were set a priori to achieve a high power. Analyses conducted with G*power (α = .05) indicated that assuming effect sizes equal to those observed in the explicit identification test of Study 1a, our sample size (64 participants per group) yielded a power of 1 for comparisons against chance.

4.1.2 Materials and Procedure

The study was run online on Qualtrics (https://www.qualtrics.com/), using a survey template compatible with tablets and regular computers. The participants were randomly assigned to the first-order or second-order conditions.

At the beginning of the experiment, the participants were told that they would see a video with the following written message, "*You will see the same video twice to ensure that you can process it fully. The video will begin automatically. In this video, you will see two new objects and a person asking questions using a new word. Please do not forget to switch ON your sound*." Next, in the familiarization phase, the participants saw a familiarization video lasting 52 seconds, twice. We used the videos of Study 1a in the first-order condition and the

videos of Study 1b in the second-order condition. In the first-order condition, the "target" was the object that the actress could not see when she asked about the location of the "tralet" ; in the second-order condition, the "target" was the object initially placed in the central box with no backside, i.e., the object whose former location (now empty) was visible for the actress when she asked about the location of the "tralet". After seeing the familiarization videos, the participants were enrolled in the test phase. In the latter, the participants were asked, "*Which object is the tralet?"* (identification question). They could answer by selecting the picture of one of the two unfamiliar objects from the familiarization videos, each of them shown against a black background (see Figure S4 panel A in Supplementary Materials). Next, the participants were asked to drag a slider to indicate how certain they were about their answer (using a continuous scale ranging from 0/completely uncertain to 100/completely certain; see Figure S4 panel B in Supplementary Materials). We collected certainty scores in adults because we anticipated that they would perform at ceiling when identifying the referent of the novel label in all conditions. By asking them to rate how certain they were about their answers, we aimed to collect a more fine-grained measure of their confidence. We did not collect certainty scores in the Studies with children (Pilot S1, 1a and 1b) because this type of measure is not easy to use with young participants.

During the familiarization phase, we counterbalanced the same factors as in Study 1a.

The same novel label (the nonsense word "tralet") was always used to refer to the object that the female actor was searching for. During the familiarization phase, we counterbalanced the same factors as in Studies 1a and 1b. During the test phase, the two unfamiliar objects were presented in a fixed manner (i.e., the red object in the first position and the purple object in the second position).

After the experiment, the participants were tested on an attention check question (see Supplementary Materials for procedural details). The participants who failed in the attention check question were excluded from the analysis.

4.1.3 Data Analysis

The statistical tests of Study 2 used the same software and followed the same general analysis procedure as in Studies 1a and 1b.

4.2 Results and Discussion

In Study 2, the participants were more likely to select the target than predicted by chance in both conditions (first-order condition: 62 successes out of 64, $p < .001$, $g = .47$; second-order condition: 45 successes out of 64, $p = .0015$, $g = .20$, binomial tests see Figure 3 panel B). However, the performance of the participants was significantly better in the first-order condition than in the second-order condition ($p < .001$, Fisher's exact test).

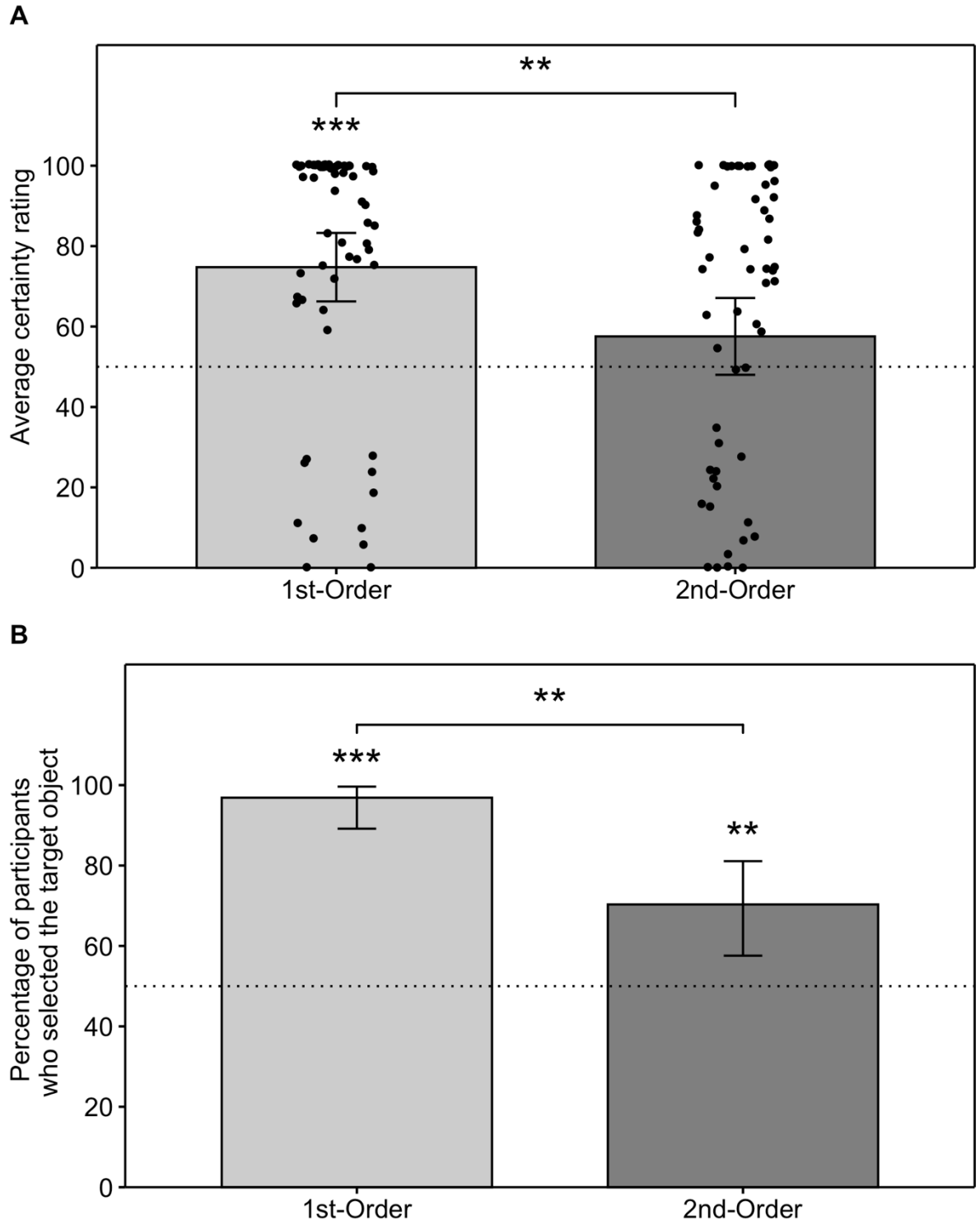
The average certainty score predicted by chance was 50 (since the participants could assign a certainty score ranging from 0 to 100). As Figure 3 panel A shows, the participants' average certainty score was significantly higher than that predicted by chance only in the first-order condition ($M = 74.8$, $SD = 34.1$, $Z = 1719$, $p < .001$, $r = .65$, Wilcoxon signed-rank test), but not in the second-order condition ($M = 57.5$, $SD = 38.3$, $Z = 1198$, $p = .19$, $r = .19$, Wilcoxon signed-rank test; $BF_{01} = 3.69$, Bayesian Wilcoxon signed-rank test). In fact, the participants' certainty scores were significantly lower in the second-order condition than in the first-order condition ($U = 2641$, $p = .0042$, $r = .29$, Mann-Whitney U-test).

In Study 2, the performance of adult participants on the second-order test suggests that they can use representations of Socratic ignorance to interpret requests for information. However, adults' performance was worse, and their certainty was lower when they had to rely

on attributions of Socratic ignorance (in the second-order condition), than when they could merely rely on simple knowledge tracking (in the first-order condition).

Figure 3.

Results of Study 2 per Condition; Panel A: Average Certainty Ratings; Panel B: Percentage of Participants Successful in the Explicit Identification Test.



Note: The dotted lines represent the level of performance predicted by chance (i.e., an average rating of 50 in panel A and 50% in panel B). In the first-order condition, the "target" was the object that the actress could not see when she asked about the location of the "tralet"; in the second-order condition, the "target" was the object initially placed in the central box with no backside, i.e., the object whose former location (now empty) was visible for the actress when she asked about the location of the "tralet". Error bars represent 95% CI. Panel A: Comparisons against chance by one-sample Wilcoxon signed-rank tests and comparisons between conditions by Wilcoxon signed-rank tests. Panel B: Comparisons against chance by binomial tests and comparison between studies by Fisher's exact test.

**: $p < .01$, ***: $p < .001$

The results of Study 2 suggest that adults may simplify the problem of interpreting information requests by using simple knowledge tracking rather than representing Socratic ignorance. This hypothesis predicts that when interpreting questions, adults exhibit a bias toward assuming that speakers can request information about things that they do not know, even when there are no reasons to assume that speakers are aware of their ignorance. We tested this prediction in Study 3 by conceptually replicating Study 2, while adding a third condition that flipped the logic of the second-order test. In this "heuristic condition," the speaker asked a question about the location of an object using a novel label. The label was ambiguous and could refer to one of the two objects. The speaker did not know about the location of one of the two potential referents of the novel label; yet, he could not see that this object had been displaced. Thus, he had illusory knowledge regarding the location of this object. The other potential referent of the label was visible to the speaker, who thus had real knowledge about the location of that object. In this heuristic condition, simple knowledge tracking should yield the selection of one referent for the novel label (the object whose location is unknown to the speaker). In

contrast, in the heuristic condition, tracking Socratic ignorance should result in assuming that both unfamiliar objects are equally unlikely to be the label's referent (since the speaker knows about the location of one object and believes that he knows about the location of the other object).

5 Study 3

5.1 Methods

5.1.1 Participants

We switched language (from French to English) from Study 2 to Study 3 to access more participants on the online recruitment platform. We tested three groups of sixty-four adult native English speakers (first-order condition: 31 females, 33 males; M_{age} = 23.7 years; *SD* = 4.47; age range: 18–35 years; second-order condition: 32 females, 32 males; M_{age} = 24.9 years; *SD* = 5.59; age range: 18–35 years; heuristic condition: 30 females, 33 males, 1 other; M_{age} = 25.9 years; *SD* = 5.26; age range: 18–35 years). The participants were recruited using the same online platform as in Study 2. The sample sizes, inclusion, and exclusion criteria were the same as in Study 2, except for the inclusion criteria of first language and nationality (we included only native English speakers from the United Kingdom in Study 3). We excluded three participants (one per condition), for failing on the attention check question at the end of the procedure.

5.1.2 Materials and Procedure

Study 3 followed the same procedure as Study 2, with the following exceptions: The actor was a male native English speaker in all the videos of Study 3; the verbal script he used in the video was adapted to English from the script used for the videos of Studies 1a-b and 2; when asking about the location of the novel object, the actor used the novel label "dollow" instead of "tralet." Thus, after he returned through the curtains and pretended to search for an

object, he put his hands on his hips, and asked, "*Where is the dollow?… Where did the dollow go?… Where could the dollow be?*".

Apart from these differences, the events of the familiarization video were the same in Studies 2 and 3 for the first-order and second-order conditions. In Study 3, we also tested a group of participants in a third condition, called the "heuristic" condition, in which we pitted knowledge against second-order ignorance.

The heuristic condition followed the same procedure as the first- and second-order conditions, except for the boxes used in the familiarization videos. In the heuristic condition, only one of the peripheral boxes had no backside, whereas the three other boxes had an opaque backside (the second peripheral box, and the two central boxes, see Figure 4 panel C1). Thus, from his perspective, the male actor was able to only see inside the box with no backside. After placing the two unfamiliar objects inside the central boxes, the male actor left the scene, and the objects were displaced, as in the first- and second-order conditions (Figure 4, panels C2 and C3). Thus, when the male actor returned after the displacement of the unfamiliar objects, he was able to see one of the unfamiliar objects, but not the other (see Figure S3 panel C in the Supplementary Materials). Moreover, from his viewpoint, he could not see that the object initially located in the central box with a backside had been displaced (we call this object the "target" when reporting the analysis and results in the heuristic condition, Figure 4 panels C4, C5, and C6), thus making him unaware of his ignorance of this object's location. Examples of the familiarization videos of Study 3 are in the supplemental materials (Videos S3–S5 in the Supplementary Materials).

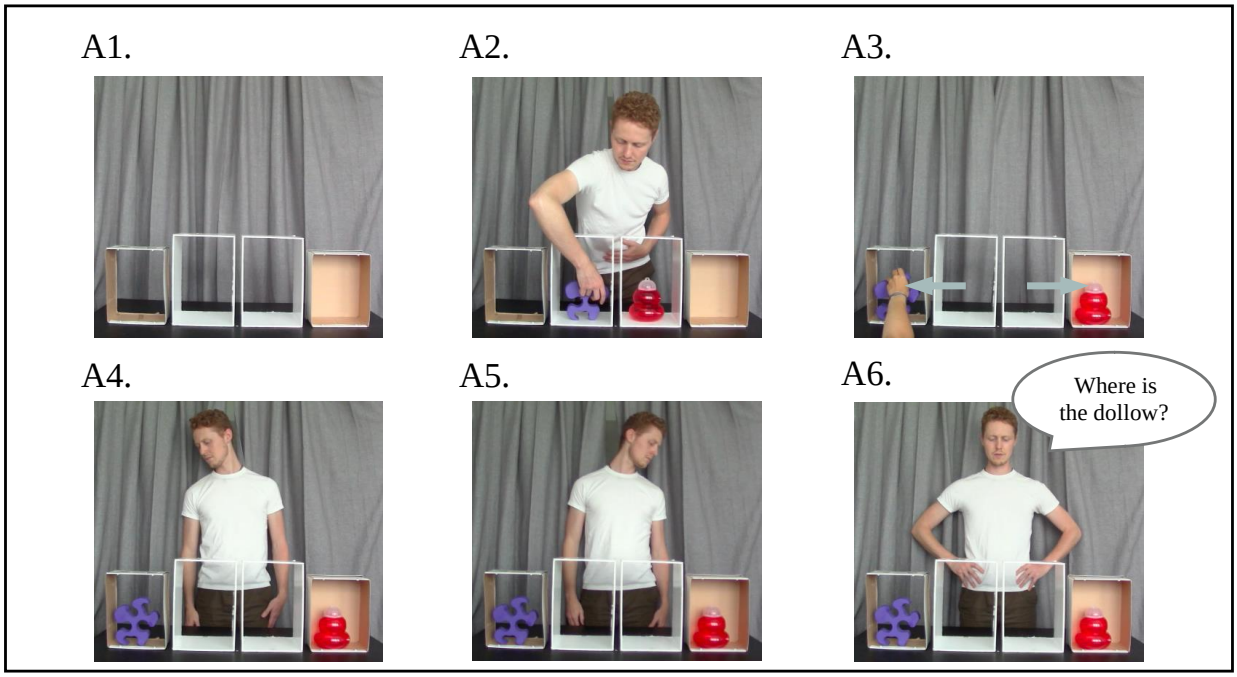
The same label ("dollow") was always used to refer to the object that the male actor was searching for. During the familiarization and test phases, we counterbalanced the same factors as in Study 2.

After watching the familiarization videos, the participants were enrolled in the test phase that unfolded as in Study 2, except for the language used (English).

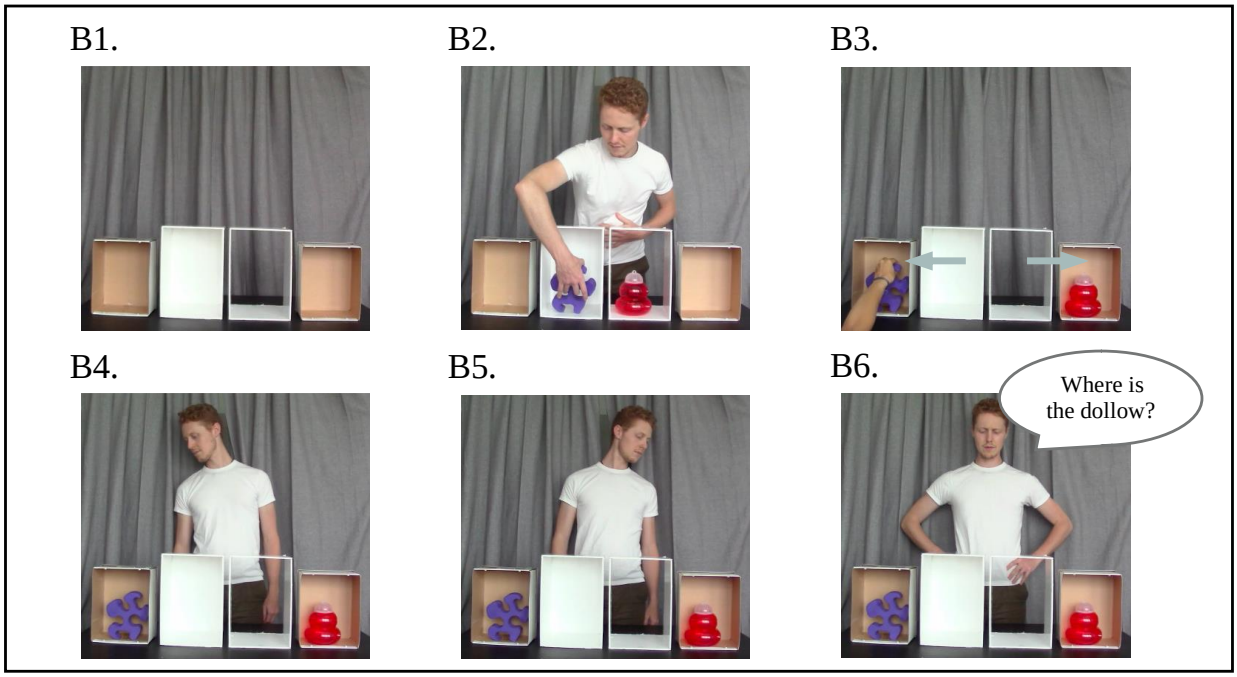
Figure 4.

Critical Events of Study 3.

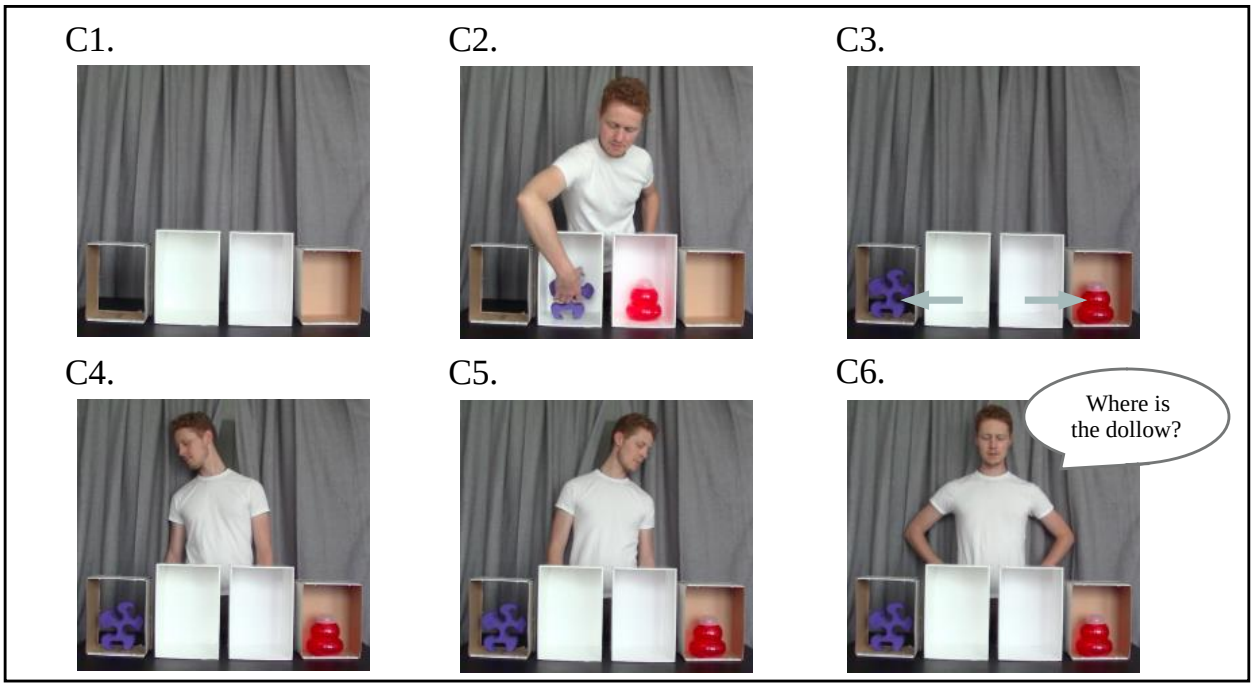
A. 1st Order condition



B. 2nd Order condition



C. Heuristic condition



Note: Panels A (A1–6): Photographs from the familiarization of the first-order test condition. Panels B (B1–6): Photographs from the familiarization of the second-order condition. Panel C (C1–6): Photographs from the familiarization of the heuristic condition.

5.1.3 Data Analysis

Unless specified, the statistical analysis procedures of Study 3 were the same as those in Study 2.

5.2 Results and Discussion

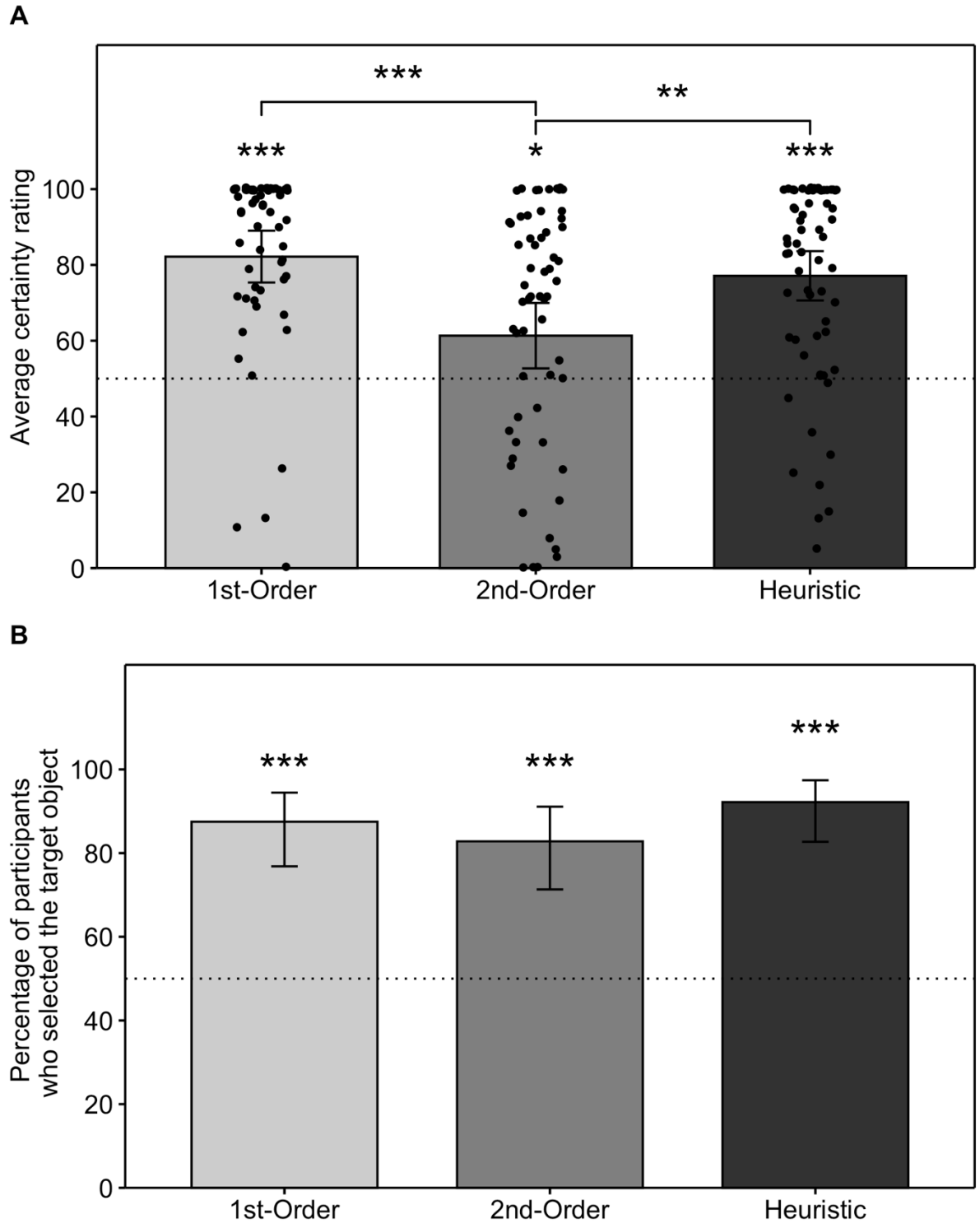
First, as shown in Figure 5 panel B, we analyzed the participants' performance in the first- and second-order conditions (a conceptual replication of Study 2). In the first-order condition, the participants were more likely to select the object that the male actor could not see when asking the question (56 choices out of 64, $p < .001$, $g = .37$, binomial test). In the

second-order condition, the participants were more likely to select the object whose past empty location was visible to the male actor when asking the question (53 successes out of 64, $p < .001$, $g = .33$, binomial test). Thus, Study 3 confirmed that adults could use both simple knowledge tracking and representations of Socratic ignorance to disambiguate questions. Unlike in Study 2, the participants were not significantly less likely to succeed in the identification test in the first-order condition than in the second-order condition test ($p = .62$, Fisher's exact test). We cannot explain this difference between the results of Studies 2 and 3 with certainty.

As Figure 5 panel A shows, participants' average certainty scores were significantly higher than predicted by chance in the first-order condition ($M = 82.2$, $SD = 27.4$, $Z = 1875.5$, $p < .001$, $r = .80$, Wilcoxon signed-rank test) and in the second-order condition ($M = 61.3$, $SD = 34.6$, $Z = 1344$, $p = .021$, $r = .33$, Wilcoxon signed-rank test). As in Study 2, the participants' certainty scores were significantly lower in the second-order than in the first-order condition ($U = 2883.5$, $p < .001$ $r = .41$, Mann-Whitney U-test).

Figure 5.

Results of Study 3 per Condition; Panel A: Average Certainty Ratings; Panel B: Percentage of Participants Successful in the Explicit Identification Test.



Note: The dotted lines represent the level of performance predicted by chance (i.e., an average rating of 50 in panel A and 50% in panel B). In the first-order condition, the "target" was the object that the actor could not see when he asked about the location of the "dollow" ; in the second-order condition, the "target" was the object that was initially placed in the central box with no backside, i.e., the object whose former location (now empty) was visible for the actor when he asked about the location of the "dollow" ; in the heuristic condition the "target" was the object initially located in the central box with a backside, i.e., the object that the actor could not see when he asked about the location of the "dollow". Error bars represent 95% CI. Panel A: Comparisons against chance by one-sample Wilcoxon signed-rank tests and comparisons between conditions by Wilcoxon signed-rank tests. Panel B: Comparisons against chance by binomial tests and comparison between studies by Fisher's exact test.

*: $p < .05$, **: $p < .01$, ***: $p < .001$.

Following this, we performed analyses including data from the heuristic condition. In this condition, the participants identified the object displaced unbeknownst to the male actor as the referent of his question more often than predicted by chance (59 choices out of 64, $p < .001$, $g = .42$, binomial test). Thus, the adults assumed that the male actor requested information about the object whose location he was unaware of, even though he had not seen that this object had been displaced. This result is remarkable, given that in the second-order condition, adult participants demonstrated their capacity to take into account the male actor's ignorance of his ignorance of the object's location.

The participants' certainty scores were significantly higher than predicted by chance in the heuristic condition ($M = 77.1$, $SD = 26.0$, $Z = 1903$, $p < .001$, $r = .83$, Wilcoxon signed-rank test). Certainty scores did not differ significantly across the first-order and the heuristic condition ($U = 2364$, $p = .12$, $r = .15$, Mann-Whitney U-test; $BF_{01} = 2.89$, Bayesian Mann-

Whitney U-test). Conversely, certainty scores were significantly higher in the heuristic condition than in the second-order condition ($U = 1469$, $p = .006$, $r = -.28$, Mann-Whitney U-test).

This pattern of results suggests that adults gave more weight to simple knowledge tracking than to representations of Socratic ignorance when interpreting the meaning of questions. Just like in Study 2, Study 3's participants selected the referent that was consistent with tracking Socratic ignorance in the second-order condition, but with a much lower certainty than in the first-order and heuristic conditions.

Moreover, in the heuristic condition, simple knowledge tracking mechanisms should yield the inference that the male actor is asking about the location of one specific object (the one whose location he is ignorant of). By contrast, tracking Socratic ignorance should yield the inference that the speaker is equally likely to ask about the location of any of the two unfamiliar objects. The results of the heuristic condition show that the participants selected a referent that was consistent with simple knowledge tracking, with a level of certainty comparable to that observed in the first-order condition. Thus, representations of Socratic ignorance did not interfere with the participants' simple knowledge tracking in any detectable manner when they interpreted the experimenter's request for information.

The results of Study 3's heuristic condition strongly suggest that adult participants prioritize simple knowledge tracking over representation of Socratic ignorance, with one caveat: when answering the test question, the participants were forced to choose between the two unfamiliar objects present in the videos. Perhaps they chose the object that was not visible to the experimenter because it was the best available option, even though they would have preferred to answer that the novel label did not refer to any of the two unfamiliar objects. We addressed this issue in Study 4.

6 Study 4

6.1 Methods

6.1.1 Participants

We tested sixty-four adult native English speakers (32 females, 31 males, 1 other; M_{age} = 26.1 years; *SD* = 5.44; age range: 18–35 years). The recruitment procedure, sample sizes, inclusion, and exclusion criteria were the same as in Study 3. We excluded only one participant, for failing on the attention check question at the end of the procedure.

6.1.2 Materials and Procedure

Study 4 used the same materials and procedure as Study 3's heuristic condition, except for the options that the participants could choose from during the test phase when answering the identification question ("*Which object is the dollow?"*). In Study 4, the participants could answer either by selecting the picture of one of the two unfamiliar objects from the familiarization videos, or by answering "*None of the above*". Next, just as in Study 3, the participants were asked to drag a slider to indicate how certain they were about their answer (see Figure S6 panel B in Supplementary Materials).

6.1.3 Data Analysis

The statistical analysis procedures of Study 4 were the same as those in Studies 2-3.

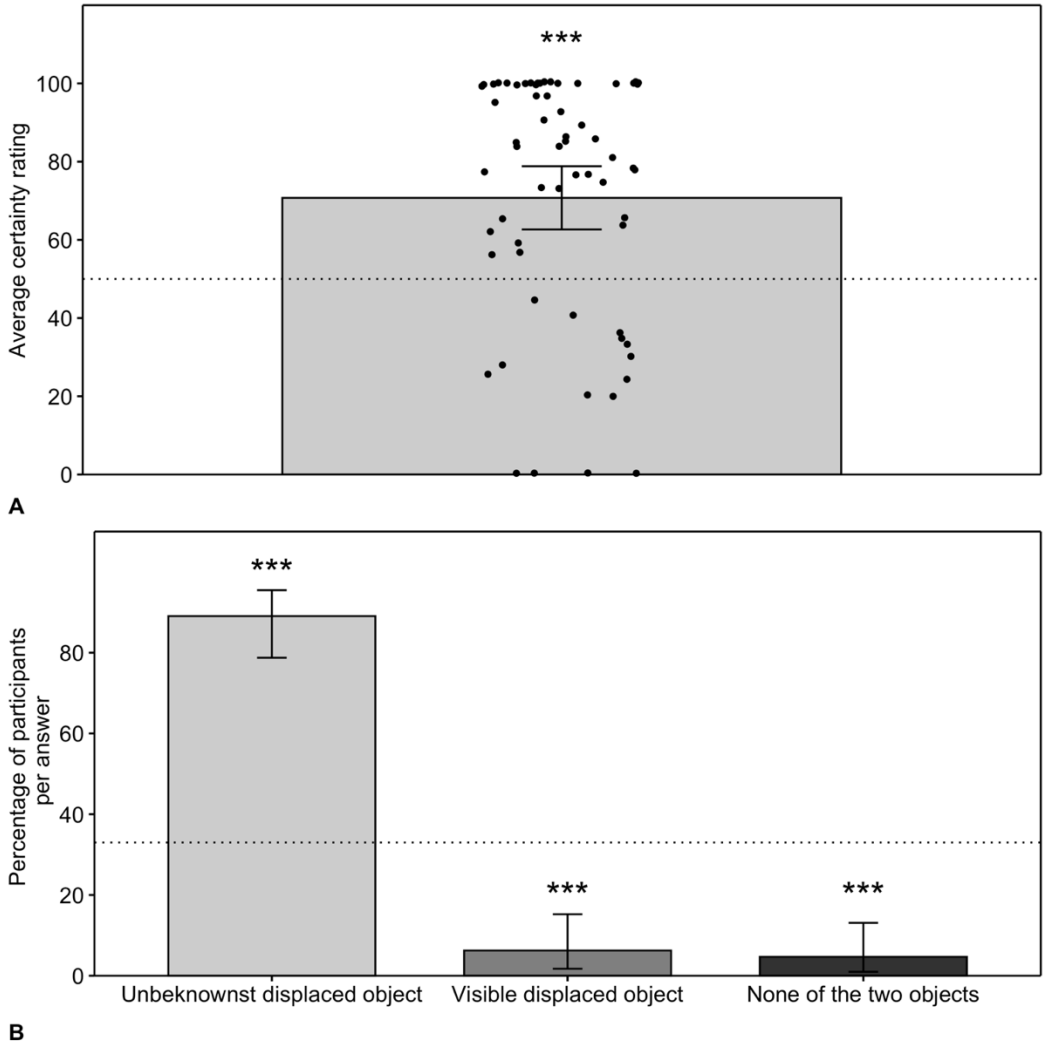
6.2 Results and Discussion

In Study 4, the participants identified the object displaced unbeknownst to the male actor as the referent of his question more often than predicted by chance, i.e., 1/3 (57 choices out of 64, $p < .001$, $g = .56$, binomial test, see Figure 6). In contrast, the participants answered by selecting the two other options less often than predicted by chance (object visible to the experimenter: 4 choices out of 64, $p < .001$, $g = -.27$, none of the objects: 3 choices out of 64, $p < .001$, $g = -.28$, binomials tests). Thus, just like in Study 3, the adults assumed that the male

actor requested information about the object whose location he was ignorant about, even though he had not seen that this object had been displaced. Also, as shown in Figure 6, the participants' average certainty score was significantly higher than predicted by chance (M = 70.7, SD = 32.3, Z = 1669, $p < .001$, r = .61, Wilcoxon signed-rank test). In short, Study 4's results confirm those of Study 3's heuristic condition, in a set-up in which the participants could answer that the speaker did not refer to any of the two unfamiliar objects.

Figure 6.

Results of Study 4; Panel A: Average Certainty Ratings; Panel B: Percentage of Participants per Answer in Explicit Identification Test.



Note: The dotted lines represent the level of performance predicted by chance (i.e., an average rating of 50 in panel A and 50% in panel B). Error bars represent 95% CI. Panel A: Comparisons against chance by one-sample Wilcoxon signed-rank tests. Panel B: Comparisons against chance by binomial tests.

***: $p < .001$.

7 General discussion

We investigated the mechanism supporting human beings' interpretation of requests for information, one of the most central functions of interrogative sentences, in six studies testing toddlers (Pilot S1), children (Studies 1a-b), and adults (Studies 2-4). Our results suggest that the interpretation of requests for information relies primarily on simple knowledge tracking, rather than on the representation of what people know that they do not know (Socratic ignorance attributions). First, we tested toddlers' use of representations of Socratic ignorance to interpret the meaning of requests for information (Pilot S1). The results supported the null hypothesis. Subsequent studies investigated more systematically whether the interpretation of requests for information is based on simple knowledge tracking or on representations of Socratic ignorance. Five- to seven-year-old children showed no tendency to rely on representation of Socratic ignorance to interpret questions, even when considering only the performance of participants with high scores on second-order false belief tasks (Study 1b). In contrast, five- to seven-year-old children succeeded easily in identifying the referent of a speaker's question when disambiguation could be achieved through simple knowledge tracking (Study 1a). Adults were able to use both simple knowledge tracking and representations of Socratic ignorance to disambiguate the meaning of the questions. However, they were more confident in their identification of a speaker's referent when interpreting requests for information could be achieved by simple knowledge tracking than when representations of Socratic ignorance were needed (Studies 2-3). Moreover, adults showed a systematic bias

toward assuming that speakers request information regarding what they do not know, even when speakers have no reason to be aware of their ignorance (Study 3, heuristic condition, Study 4). In short, our results suggest that the interpretation of requests for information is primarily guided by simple knowledge tracking rather than by representations of Socratic ignorance, throughout one's life.

To clarify, we do not claim that humans never appeal to the representations of Socratic ignorance to interpret requests for information. In fact, we demonstrated that adults can do so in the second-order condition of Studies 2-3. Similarly, we do not claim that simple knowledge tracking is always activated by default, whereas representations of Socratic ignorance are only activated in specific instances. Our results are compatible with the perspective that when interpreting speakers' meanings, adults integrate information coming from multiple cognitive systems in parallel (e.g., Degen & Tanenhaus, 2019), including information coming both from mechanisms representing Socratic ignorance, and from simple knowledge tracking systems. Importantly, our data suggest that, in many cases, the interpretation of requests for information relies more strongly on simple knowledge tracking than on representations of Socratic ignorance. Future research should investigate whether and how the prevalence of simple knowledge tracking over representations of Socratic ignorance is influenced by contextual factors, and builds on differences in activation frequency, speed, ease of processing, or in the weight given to the output of these two mechanisms.

It is noteworthy that simple knowledge tracking can also deal with fairly complex cases involving a speaker's complete ignorance, a specific form of ignorance of one's ignorance. In the experiments we conducted, we focused on how participants may distinguish illusory knowledge—when individuals mistakenly believe themselves to be knowledgeable about a piece of information—from Socratic ignorance. It is important to note that, agents can be ignorant of their ignorance because they have no beliefs about something. For example,

someone who knows nothing about "TOI 700d" and does not even know that this planet exists (and thus, has no beliefs about it), is in a state of complete ignorance about TOI 700d. Understandably, someone who has no beliefs whatsoever about an entity or event is unlikely to refer to it and thus, to request information about it. Therefore, it is possible to exclude entities that a speaker is completely unaware of, as possible targets of her requests for information by using simple knowledge tracking.

Four reasons may jointly contribute to the primacy of simple knowledge tracking in the interpretation of requests for information. First, simple knowledge tracking is less cognitively complex and less costly than representations of Socratic ignorance. Monitoring speakers' perspectives and knowledge is not cost-free, especially when they differ from one's own; in addition, it can be challenging to track what others know, or are ignorant of, even for adults (Barr, 2008; Cane et al., 2017; Epley et al., 2004; Hanna et al., 2003; Keysar et al., 2000; Nilsen & Graham, 2009; Samuel et al., 2019; Wu et al., 2013). Now, each representation of Socratic ignorance embeds a representation of first-order ignorance, thus making the former even more complex and cognitively costly than the latter (representing that "John knows that John does not know p" is more cognitively demanding than representing "John does not know p").

Second, human adults, infants, and non-human primates spontaneously and efficiently discriminate what people know from what they are unaware of (e.g., for a review, see Phillips et al., 2020). It is not known whether the mechanisms supporting fast and efficient representations of knowledge can track recursive mental states embedded within mental states, such as Socratic ignorance. In fact, many authors have suggested that core abilities used to track others' knowledge need not involve complex representations of mental states decoupled from reality (Apperly & Butterfill, 2009; Burge, 2018; Flavell, 1988; Horschler et al., 2019; Low et al., 2016; Martin & Santos, 2016; Nagel, 2017; Perner, 1989; Phillips et al., 2020; Phillips & Norby, 2021; Wellman, 1992; Westra & Nagel, 2021). For example, some theories

posit that simple forms of knowledge tracking might involve the representation of non-representational relations (e.g., registrations or sensing) between agents and actual objects, properties, or events (Apperly & Butterfill, 2009; Burge, 2018; Low et al., 2016). In these non-representational theories, when an agent is ignorant about something, no relationship is established between the agents and what they are ignorant of, and their ignorance might simply not be represented at all. Generally speaking, the exact nature and complexity (or lack thereof) of fast and efficient representations of knowledge are yet to be fully elucidated empirically. However, it is possible that some of the mechanisms that support fast and efficient tracking of others' knowledge may not be able to track Socratic ignorance.

Third, if someone is aware of not knowing a piece of information, one can be reasonably certain that she/he lacks that piece of information (leaving aside rare exceptions, such as blindsight, see Weiskrantz et al., 1974). The reverse, however, is not true: someone may very well be ignorant about a piece of information without being aware of her/his ignorance. Thus, learning that someone knows about her ignorance is reliable evidence of her ignorance. By contrast, learning that someone is ignorant about a piece of information is often insufficient to establish that she knows about her ignorance. As a result, for each given piece of information, more information can be gained about people's ignorance of that information than about their awareness of their ignorance of that information. In short, relying more strongly on simple knowledge tracking than on attributions of Socratic ignorance may be rational, since one should have more confidence in one's information about people's knowledge and ignorance, than in one's information about what people know that they do not know.

Fourth, assumptions of competence triggered by requests for information may also contribute to explaining why listeners may sometimes disregard information about what speakers are unaware of not knowing. One central function of requests for information is to communicate what kind of information might be cognitively useful to the people formulating

such requests. Thus, requests for information convey a very special presumption of competence on behalf of the people formulating them. They imply that the people requesting information have sufficient knowledge to identify the kind of information that is cognitively useful for them. Part of this knowledge, of course, is knowledge of what they are ignorant of. Thus, requests for information convey a presumption of knowledge of one's ignorance attached to the person formulating the request. Such a presumption of competence may override or mask pre-existing attributions of ignorance of one's ignorance.

The results of the current studies broaden the horizon of research directions. First, we identified a cognitive ability, the representation of Socratic ignorance, which is crucial in representing information search in others. Future studies should identify when and how representations of Socratic ignorance are triggered, how they operate, and their role in the representation of information search. Moreover, our studies reveal a developmental change from childhood to adulthood. Unlike children, adults were able to use representations of Socratic ignorance to disambiguate the meaning of requests for information. This developmental change was unrelated to the emergence of the competence to form complex second-order representations of mental states (such as representations of Socratic ignorance). Indeed, in Study 1b, children who had a high score on second-order false belief task were able to answer complex questions about knowledge about knowledge, and beliefs about beliefs. Yet, they made little use of their capacity to represent second-order mental states when disambiguating requests for information. Thus, future studies should investigate when and how representations of Socratic ignorance start to be used to interpret information search, and questions.

Second, we found that the complex problem of interpreting requests for information is likely to be simplified by using heuristics, such as using simple knowledge tracking rather than relying on representations of Socratic ignorance. This result highlights that representing

ignorance is a complex problem that may be addressed by using not just one, but many different kinds of cognitive mechanisms, including simple heuristic and complex representations of mental states. Future research should investigate the nature of the cognitive mechanisms supporting human representations of ignorance, and whether they are supported by a unique mechanism or by multiple distinct mechanisms.

Third, in our studies, we kept the speakers' characteristics fixed. Importantly, individuals are more likely to request information that they lack, in domains that they find interesting. Thus, future research should investigate whether and how the characteristics of informants (such as their competence, knowledge, honesty, or information about their interests) modulate the interpretation of their requests for information. Fourth, genuine requests for information convey a presumption about the desirability of a piece of information (Wilson, 2012). Our data suggest that a lack of information crucially contributes to its desirability. Yet, many other features may make a piece of information desirable. Thus, future work should investigate how the desirability of a piece of information is represented and how it guides the interpretation of requests for information.

9 References

Apperly, I. A., & Butterfill, S. A. (2009). Do humans have two systems to track beliefs and belief-like states? *Psychological Review*, *116*(4), 953-970. https://doi.org/10.1037/a0016923

Arslan, B., Hohenberger, A., & Verbrugge, R. (2017). Syntactic Recursion Facilitates and Working Memory Predicts Recursive Theory of Mind. *PLOS ONE*, *12*(1), e0169510. https://doi.org/10.1371/journal.pone.0169510

Arslan, B., Verbrugge, R., Taatgen, N., & Hollebrandse, B. (2020). Accelerating the Development of Second-Order False Belief Reasoning : A Training Study With Different Feedback Methods. *Child Development*, *91*(1), 249-270. https://doi.org/10.1111/cdev.13186

Bach, K., & Harnish, R. M. (1979). *Linguistic communication and speech acts*. MIT Press.

Barr, D. J. (2008). Pragmatic expectations and linguistic evidence : Listeners anticipate but do not integrate common ground. *Cognition*, *109*(1), 18-40. https://doi.org/10.1016/j.cognition.2008.07.005

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, *67*(1). https://doi.org/10.18637/jss.v067.i01

Beck, A. A., Rossion, B., & Samson, D. (2018). An objective neural signature of rapid perspective taking. *Social Cognitive and Affective Neuroscience*, *13*(1), 72-79. https://doi.org/10.1093/scan/nsx135

Begus, K., Gliga, T., & Southgate, V. (2014). Infants Learn What They Want to Learn : Responding to Infant Pointing Leads to Superior Learning. *PLOS ONE*, *9*(10), e108817. https://doi.org/10.1371/journal.pone.0108817

Begus, K., & Southgate, V. (2012). Infant pointing serves an interrogative function. *Developmental Science*, *15*(5), 611-617. https://doi.org/10.1111/j.1467-7687.2012.01160.x

Bergelson, E., & Swingley, D. (2012). At 6–9 months, human infants know the meanings of many common nouns. *Proceedings of the National Academy of Sciences*, *109*(9), 3253-3258. https://doi.org/10.1073/pnas.1113380109

Bohn, M., & Köymen, B. (2018). Common Ground and Development. *Child Development Perspectives*, *12*(2), 104-108. https://doi.org/10.1111/cdep.12269

Bromberger, S. (1992). *On What We Know We Don't Know : Explanation, Theory, Linguistics, and How Questions Shape Them*. University of Chicago Press.

Brown-Schmidt, S., & Fraundorf, S. H. (2015). Interpretation of informational questions modulated by joint knowledge and intonational contours. *Journal of Memory and Language*, *84*, 49-74. https://doi.org/10.1016/j.jml.2015.05.002

Brown-Schmidt, S., Gunlogson, C., & Tanenhaus, M. K. (2008). Addressees distinguish shared from private information when interpreting questions during interactive conversation. *Cognition*, *107*(3), 1122-1134. https://doi.org/10.1016/j.cognition.2007.11.005

Burge, T. (2018). Do infants and nonhuman animals attribute mental states? *Psychological Review*, *125*(3), 409-434. https://doi.org/10.1037/rev0000091

Cane, J. E., Ferguson, H. J., & Apperly, I. A. (2017). Using perspective to resolve reference : The impact of cognitive load and motivation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *43*(4), 591-610. https://doi.org/10.1037/xlm0000345

Carpenter, M., Call, J., & Tomasello, M. (2002). A new false belief test for 36-month-olds. *British Journal of Developmental Psychology*, *20*(3), 393-420. https://doi.org/10.1348/026151002320620316

Chouinard, M. M. (2007). Children's Questions : A Mechanism for Cognitive Development [Review of *Children's Questions : A Mechanism for Cognitive Development*, par P. L. Harris & M. P. Maratsos]. *Monographs of the Society for Research in Child Development*, *72*(1), i-129.

Clopper, C. J., & Pearson, E. S. (1934). The Use of Confidence or Fiducial Limits Illustrated in the Case of the Binomial. *Biometrika*, *26*(4), 404-413. https://doi.org/10.1093/biomet/26.4.404

Dautriche, I., Goupil, L., Smith, K., & Rabagliati, H. (2021). Knowing How You Know : Toddlers Reevaluate Words Learned From an Unreliable Speaker. *Open Mind*, *5*, 1-19. https://doi.org/10.1162/opmi_a_00038

Degen, J., & Tanenhaus, M. K. (2019). Constraint-Based Pragmatic Processing. In C. Cummins & N. Katsos (Éds.), *The Oxford Handbook of Experimental Semantics and Pragmatics* (p. 20-38). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780198791768.013.8

Dink, J. W., & Ferguson, B. (2015). *EyetrackingR: An R Library for Eye-tracking Data Analysis*. http://www.eyetrackingr.com.

Epley, N., Keysar, B., Van Boven, L., & Gilovich, T. (2004). Perspective Taking as Egocentric Anchoring and Adjustment. *Journal of Personality and Social Psychology*, *87*(3), 327-339. https://doi.org/10.1037/0022-3514.87.3.327

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3 : A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175-191. https://doi.org/10.3758/BF03193146

Flavell, J. H. (1988). The development of children's knowledge about the mind : From cognitive connections to mental representations. In *Developing theories of mind* (p. 244-267). Cambridge University Press.

Furlanetto, T., Becchio, C., Samson, D., & Apperly, I. (2016). Altercentric interference in level 1 visual perspective taking reflects the ascription of mental states, not submentalizing. *Journal of Experimental Psychology: Human Perception and Performance*, *42*(2), 158-163. https://doi.org/10.1037/xhp0000138

Groenendijk, J. A. G., & Stokhof, M. J. B. (1984). *Studies on the Semantics of Questions and the Pragmatics of Answers* [PhD Thesis]. Univ. Amsterdam.

Grosse, G., Moll, H., & Tomasello, M. (2010). 21-Month-olds understand the cooperative logic of requests. *Journal of Pragmatics*, *42*(12), 3377-3383. https://doi.org/10.1016/j.pragma.2010.05.005

Grosse, G., & Tomasello, M. (2012). Two-year-old children differentiate test questions from genuine questions. *Journal of Child Language*, *39*(1), 192-204. https://doi.org/10.1017/S0305000910000760

Grueneisen, S., Wyman, E., & Tomasello, M. (2015). "I Know You Don't Know I Know…" Children Use Second-Order False-Belief Reasoning for Peer Coordination. *Child Development*, *86*(1), 287-293. https://doi.org/10.1111/cdev.12264

Hanna, J. E., Tanenhaus, M. K., & Trueswell, J. C. (2003). The effects of common ground and perspective on domains of referential interpretation. *Journal of Memory and Language*, *49*(1), 43-61. https://doi.org/10.1016/S0749-596X(03)00022-6

Heinze, G., Ploner, M., & Jiricka Lena. (2020). *logistf : Firth's Bias-Reduced Logistic Regression* (R package version 1.24) [Computer software].

Horschler, D. J., Santos, L. R., & MacLean, E. L. (2019). Do non-human primates really represent others' ignorance? A test of the awareness relations hypothesis. *Cognition*, *190*, 72-80. https://doi.org/10.1016/j.cognition.2019.04.012

JASP Team. (2020). *JASP (Version 0.14.1)[Computer software]*. https://jasp-stats.org/

Kampa, A., & Papafragou, A. (2020). Four-year-olds incorporate speaker knowledge into pragmatic inferences. *Developmental Science*, *23*(3). https://doi.org/10.1111/desc.12920

Kampis, D., Parise, E., Csibra, G., & Kovács, Á. M. (2015). Neural signatures for sustaining object representations attributed to others in preverbal human infants. *Proceedings of the Royal Society B: Biological Sciences*, *282*(1819), 20151683. https://doi.org/10.1098/rspb.2015.1683

Karttunen, L. (1977). Syntax and semantics of questions. *Linguistics and philosophy*, *1*(1), 3-44.

Keysar, B., Barr, D. J., Balin, J. A., & Brauner, J. S. (2000). Taking Perspective in Conversation : The Role of Mutual Knowledge in Comprehension. *Psychological Science*, *11*(1), 32-38. https://doi.org/10.1111/1467-9280.00211

Khu, M., Chambers, C. G., & Graham, S. A. (2020). Preschoolers Flexibly Shift Between Speakers' Perspectives During Real-Time Language Comprehension. *Child Development*, *91*(3), e619-e634. https://doi.org/10.1111/cdev.13270

Köder, F., & Falkum, I. L. (2020). Children's metonymy comprehension : Evidence from eye-tracking and picture selection. *Journal of Pragmatics*, *156*, 191-205. https://doi.org/10.1016/j.pragma.2019.07.007

Kovács, Á. M., Tauzin, T., Téglás, E., Gergely, G., & Csibra, G. (2014). Pointing as Epistemic Request : 12-month-olds Point to Receive New Information. *Infancy*, *19*(6), 543-557. https://doi.org/10.1111/infa.12060

Kurkul, K. E., & Corriveau, K. H. (2018). Question, Explanation, Follow-Up : A Mechanism for Learning From Others? *Child Development*, *89*(1), 280-294. https://doi.org/10.1111/cdev.12726

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest Package : Tests in Linear Mixed Effects Models. *Journal of Statistical Software*, *82*(13). https://doi.org/10.18637/jss.v082.i13

Liebal, K., Behne, T., Carpenter, M., & Tomasello, M. (2009). Infants use shared experience to interpret pointing gestures. *Developmental Science*, *12*(2), 264-271. https://doi.org/10.1111/j.1467-7687.2008.00758.x

Liszkowski, U., Carpenter, M., & Tomasello, M. (2007). Pointing out new news, old news, and absent referents at 12 months of age. *Developmental Science*, *10*(2), F1-F7. https://doi.org/10.1111/j.1467-7687.2006.00552.x

Loewenstein, G. (1994). The psychology of curiosity : A review and reinterpretation. *Psychological Bulletin*, *116*(1), 75-98. https://doi.org/10.1037/0033-2909.116.1.75

Low, J., Apperly, I. A., Butterfill, S. A., & Rakoczy, H. (2016). Cognitive Architecture of Belief Reasoning in Children and Adults : A Primer on the Two-Systems Account. *Child Development Perspectives*, *10*(3), 184-189. https://doi.org/10.1111/cdep.12183

Luo, Y., & Baillargeon, R. (2007). Do 12.5-month-old infants consider what objects others can see when interpreting their actions? *Cognition*, *105*(3), 489-512. https://doi.org/10.1016/j.cognition.2006.10.007

Mangiafico, S. (2021). *rcompanion : Functions to Support Extension Education Program Evaluation* (R package version 2.3.27) [Computer software]. https://CRAN.R-project.org/package=rcompanion

Martin, A., & Santos, L. R. (2016). What Cognitive Representations Support Primate Theory of Mind? *Trends in Cognitive Sciences*, *20*(5), 375-382. https://doi.org/10.1016/j.tics.2016.03.005

Mascaro, O., & Morin, O. (2015). Epistemology for Beginners : Two- to Five-Year-Old Children's Representation of Falsity. *PLOS ONE*, *10*(10), e0140658. https://doi.org/10.1371/journal.pone.0140658

Mazzarella, D., & Pouscoulous, N. (2020). Pragmatics and epistemic vigilance : A developmental perspective. *Mind & Language*, *n/a*(n/a). https://doi.org/10.1111/mila.12287

Miller, S. A. (2009). Children's understanding of second-order mental states. *Psychological Bulletin*, *135*(5), 749-773. https://doi.org/10.1037/a0016854

Moll, H., & Tomasello, M. (2006). Level 1 perspective-taking at 24 months of age. *British Journal of Developmental Psychology*, *24*(3), 603-613. https://doi.org/10.1348/026151005X55370

Nadig, A. S., & Sedivy, J. C. (2002). Evidence of Perspective-Taking Constraints in Children's On-Line Reference Resolution. *Psychological Science*, *13*(4), 329-336. https://doi.org/10.1111/j.0956-7976.2002.00460.x

Nagel, J. (2017). Factive and nonfactive mental state attribution. *Mind & Language*, *32*(5), 525-544. https://doi.org/10.1111/mila.12157

Nilsen, E. S., & Graham, S. A. (2009). The relations between children's communicative perspective-taking and executive functioning. *Cognitive Psychology*, *58*(2), 220-249. https://doi.org/10.1016/j.cogpsych.2008.07.002

Nurmsoo, E., & Bloom, P. (2008). Preschoolers' Perspective Taking in Word Learning : Do They Blindly Follow Eye Gaze? *Psychological Science*, *19*(3), 211-215. https://doi.org/10.1111/j.1467-9280.2008.02069.x

O'Neill, D. K. (1996). Two-Year-Old Children's Sensitivity to a Parent's Knowledge State When Making Requests. *Child Development*, *67*(2), 659-677. https://doi.org/10.1111/j.1467-8624.1996.tb01758.x

O'Grady, C., Scott-Phillips, T., Lavelle, S., & Smith, K. (2020). Perspective-taking is spontaneous but not automatic. *Quarterly Journal of Experimental Psychology*, *73*(10), 1605-1628. https://doi.org/10.1177/1747021820942479

Peirce, J., Gray, J. R., Simpson, S., MacAskill, M., Höchenberger, R., Sogo, H., Kastman, E., & Lindeløv, J. K. (2019). PsychoPy2 : Experiments in behavior made easy. *Behavior Research Methods*, *51*(1), 195-203. https://doi.org/10.3758/s13428-018-01193-y

Perner, J. (1989). Is "thinking" belief? Reply to Wellman and Bartsch. *Cognition*, *33*(3), 315-319. https://doi.org/10.1016/0010-0277(89)90032-2

Perner, J., & Wimmer, H. (1985). "John thinks that Mary thinks that…" attribution of second-order beliefs by 5- to 10-year-old children. *Journal of Experimental Child Psychology*, *39*(3), 437-471. https://doi.org/10.1016/0022-0965(85)90051-7

Phillips, J., Buckwalter, W., Cushman, F., Friedman, O., Martin, A., Turri, J., Santos, L., & Knobe, J. (2020). Knowledge before Belief. *Behavioral and Brain Sciences*, 1-37. https://doi.org/10.1017/S0140525X20000618

Phillips, J., & Norby, A. (2021). Factive theory of mind. *Mind & Language*, *36*(1), 3-26. https://doi.org/10.1111/mila.12267

Pratt, C., & Bryant, P. (1990). Young Children Understand That Looking Leads to Knowing (So Long as They Are Looking into a Single Barrel). *Child Development*, *61*(4), 973-982. https://doi.org/10.1111/j.1467-8624.1990.tb02835.x

R Core Team. (2020). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Ronfard, S., Zambrana, I. M., Hermansen, T. K., & Kelemen, D. (2018). Question-asking in childhood : A review of the literature and a framework for understanding its development. *Developmental Review*, *49*, 101-120. https://doi.org/10.1016/j.dr.2018.05.002

Samson, D., Apperly, I. A., Braithwaite, J. J., Andrews, B. J., & Bodley Scott, S. E. (2010). Seeing it their way : Evidence for rapid and involuntary computation of what other people see. *Journal of Experimental Psychology: Human Perception and Performance*, *36*(5), 1255-1266. https://doi.org/10.1037/a0018729

Samuel, S., Roehr-Brackin, K., Jelbert, S., & Clayton, N. S. (2019). Flexible egocentricity : Asymmetric switch costs on a perspective-taking task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *45*(2), 213-218. https://doi.org/10.1037/xlm0000582

Searle, J. R. (1969). *Speech acts : An essay in the philosophy of language*. University Press.

Siposova, B., Grueneisen, S., Helming, K., Tomasello, M., & Carpenter, M. (2021). Common knowledge that help is needed increases helping behavior in children. *Journal of Experimental Child Psychology*, *201*, 104973. https://doi.org/10.1016/j.jecp.2020.104973

Sodian, B., Thoermer, C., & Metz, U. (2007). Now I see it but you don't : 14-month-olds can represent another person's visual perspective. *Developmental Science*, *10*(2), 199-204. https://doi.org/10.1111/j.1467-7687.2007.00580.x

Sullivan, K., Zaitchik, D., & Tager-Flusberg, H. (1994). Preschoolers can attribute second-order beliefs. *Developmental Psychology*, *30*(3), 395-402. https://doi.org/10.1037/0012-1649.30.3.395

Swingley, D. (2007). Lexical exposure and word-form encoding in 1.5-year-olds. *Developmental Psychology*, *43*(2), 454-464. https://doi.org/10.1037/0012-1649.43.2.454

Swingley, D., & Aslin, R. N. (2000). Spoken word recognition and lexical representation in very young children. *Cognition*, *76*(2), 147-166. https://doi.org/10.1016/S0010-0277(00)00081-0

Weiskrantz, L., Warrington, E. K., Sanders, M. D., & Marshall, J. (1974). Visual capacity in the hemianopic field following a restricted occipital ablation. *Brain*, *97*(1), 709-728.

Wellman, H. M. (1992). *The child's theory of mind* (p. xiii, 358). The MIT Press.

Westra, E., & Nagel, J. (2021). Mindreading in conversation. *Cognition*, *210*, 104618. https://doi.org/10.1016/j.cognition.2021.104618

Wilson, D. (2012). Metarepresentation in linguistic communication. In *Meaning and relevance* (p. 230). Cambridge University Press.

Wu, S., Barr, D. J., Gann, T. M., & Keysar, B. (2013). How culture influences perspective taking : Differences in correction, not integration. *Frontiers in Human Neuroscience*, *7*. https://doi.org/10.3389/fnhum.2013.00822

Supplementary Materials

Study Pilot S1

Methods

Participants

We tested eighteen two-and-a-half-year-old children (7 girls, 11 boys; M_{age} = 27.83 months; *SD* = 3.88; age range: 23–34 months). Five additional participants were excluded from the analysis for the following reasons: refusal to cooperate (3) and technical failure (2). The participants of Study 1 were recruited by sending letters to a randomly selected sample of toddlers born in the Lyon (France) area. Our sample sizes were set after referring to comparable studies (Nurmsoo & Bloom, 2008; Experiment 2, which reported an effect size d = 1.219 for the comparison of two-and-a-half-year-old children's performance against chance). A compromise power analysis performed with G*power (v. 3.1; Faul et al., 2007) indicated that our sample size yielded a power equal to .93 for comparison against chance by a two-tailed one-sample t-test (d = .8; α = .05).

Materials and Procedure

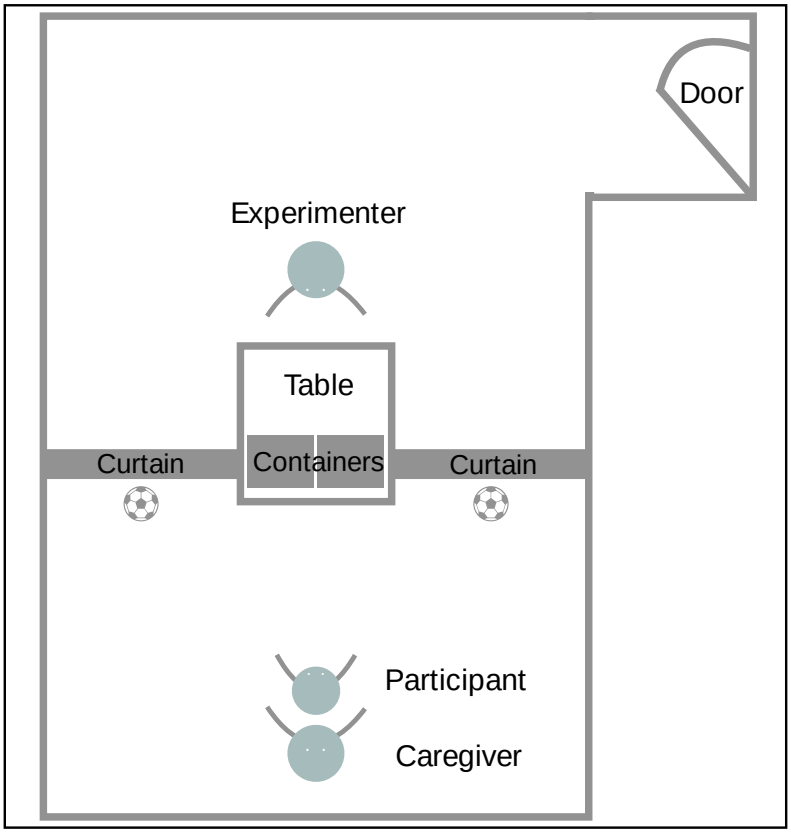
Experimental setup. Toddlers were tested in a quiet room and were accompanied by a caregiver who was instructed not to influence the participants' choices at any time point of the test phase. The participants sat on their caregivers' laps on a chair positioned against the wall of the testing room (see Figure S1 for a schematic representation of the experimental setup and photographs of critical events). A table (50x70 cm) was placed in the center of the room, in front of the participants, approximately 1.5 meters away from them. Two containers made of opaque cardboard (30x21x21 cm) were placed in a row on the table, approximately 20 cm apart from each other, one on each side of the table. The containers had no front side, so that the participant could see inside them at all times. One of the boxes (henceforth, the hiding box) had an opaque backside while the other box (henceforth, the tube) had no backside. Thus, anyone

located in front of the participant across the table could see inside the tube only, and could not see inside the hiding box. We counterbalanced the side of the table on which the hiding box was (right or left), across participants. The location of the tube varied accordingly. Moreover, two opaque curtains were hanging from the ceiling to the floor on each side of the table. Each of the curtains was positioned perpendicular to the rooms' lateral walls, and touched both the edge of the table and the wall. Thus, it was impossible for anyone located in front of the toddler across the table to see the areas located on the floor behind the curtains. These areas served as hiding locations for the balls used during the test phase. Three cameras (temporal resolution = 25 frames per second) recorded the participants' behaviors.

Figure S1.

Schematic Representation and Critical Events of Pilot S1's.

A. Schematic representation of the test phase of Study S1.



B. Pictures of the real setup of Study S1.

B1.



B2.



B3.



Note: Panel A: Schematic representation of the spatial position and orientation of the participants during the test phase of Pilot S1. Two curtains prevented the experimenter from seeing the balls, which remained visible from the toddler's viewpoint. Panel B: pictures of the real setup of Pilot S1. B1: The first experimenter places the balls in the containers. B2: A confederate displaces the balls behind the curtains while the first experimenter is absent from the room. B3: The experimenter looks towards the boxes, and asks about the location of one ball; the participant is shown answering by pointing towards one of the balls. For each sub-panel, the top left pictures show the participant from the ceiling point of view (this camera angle was used to code her pointing behaviors). The top right pictures show what could be seen from the experimenter's point of view. The bottom left pictures show a close-up of the participant (this camera angle was used to code her behaviors).

Warm-up phase. First, the experimenter crouched near the participant and showed a box containing four toys (a plush cat, a plastic duck, a plush fish, and a tiny shoe), while saying, *"I brought some toys with me… What's in this box?"* She then named each toy, before giving them to the participant, one by one. After the participants interacted for some time with each of the toys, the experimenter invited them to put them back inside the box by saying, *"Shall we put them back in the box? I have others…"* At the end of the warm-up phase, the experimenter stood up and moved across the table in front of the participants. Next, the ignorance induction phase was initiated.

Ignorance induction phase. After the warm-up phase, the experimenter showed the participant two identical colored plush balls while saying, *"Look, I brought two nice balls."* Next, she placed one ball in the hiding box and the other ball in the tube (starting with the container on the right side of the table see Figure S1 panel B1; positions are referenced from the experimenter's viewpoint). Meanwhile, the experimenter explained, *"I put this pretty ball*

here and I put this pretty ball here." Next, the experimenter pretended to receive a phone call and left the room while saying, *"Hey, my phone is ringing! I will answer and come back."* Prior to the beginning of the experiment, the caregivers were asked to close their eyes from the moment when the first experimenter left the room until the end of the experiment. While the first experimenter was away, a second experimenter, unfamiliar to the participants, entered the room (without speaking or making eye contact with the participants). She approached the table and placed each of the balls in the hiding locations on the floor behind the curtains (see Figure S1 panel B2), moving the ball inside the container on the left, behind the left curtain and the ball inside the container on the right, behind the curtain on the right. Following this, the second experimenter left the room, and the test phase began.

Test phase. At the beginning of the test phase, the first experimenter returned to the room and walked toward the table. She stopped approximately 1.5 meters away from the table, in front of the participant (see the position of the experimenter in Figure S1 panel B3). She looked toward the table and empty containers with her hands on her hips. To ensure that her gaze was not directed toward any specific container, she fixated on a discreet mark located at the center of the table. To describe the scene with a mentalistic gloss, when the first experimenter returned after the balls were displaced by the second experimenter, the former was ignorant about the location of the two balls (since both of them were placed behind the curtains and were occluded from her; see Figure S1). However, she could see that the ball initially placed in the tube was no longer there, thus informing her of her ignorance of the location of this ball (we call this ball the "target" when reporting the analysis and results of Pilot S1). Conversely, the first experimenter could not see that the ball located initially in the hiding box was no longer there, thus rendering her unaware of her ignorance of the location of that ball (we call that ball the "distractor" when reporting the analysis and results of Pilot S1). Thus, in Pilot S1, if toddlers do not take into account the experimenter's Socratic ignorance,

and if they are primarily trying to inform her (by filling gaps in her knowledge, or by correcting her false beliefs), they should be equally likely to point towards any of the balls. In contrast, if toddlers take into account the experimenter's Socratic ignorance, they should assume that she refers to the target ball, initially located in the tube.

The experimenter then looked at the participant, and asked the first prompt question: *"Well, where is the ball?"* Then, she looked around (first on her left side, next on her right side), as if searching for a ball, before looking at the participant while asking the second prompt question: *"Where did the ball go?"* Following this, she looked again toward the mark between the two boxes and asked a third prompt question (*"Where is that ball?"*). Finally, she looked at the participant, and she asked the fourth prompt question: *"<Participant's name> where is the ball?"* There was a delay of approximately 5 seconds between each prompt question. Each participant was enrolled in a single test trial (with four consecutive prompt questions).

Coding

The video recordings were coded offline frame-by-frame, for 20 consecutive seconds from the onset of the first prompt question. We coded two types of behaviors: points and looks. We measured: (i) which ball the infants first looked at after the onset of the first prompt question (i.e., the target or the distractor); (ii) the total duration of looking time toward the target and distractor; and, (iii) the proportion of target looks (number of looks toward the target/number of looks toward the target + distractor). We also collected exactly the same measures for the points. A point was defined as an extension of the infant's arm (either fully or slightly bent) and index finger or open hand, palm facing downward, in the general direction of the object (Liszkowski et al., 2006). One participant did not point toward any of the balls. For this participant, we coded the first point as missing data. The data were first coded by a primary coder. A second coder, who was unaware of the hypotheses of the study, coded 50% of the

videos. The agreement between the coders was high for each measure: duration of an action (looking: Spearman's *rho* = 0.89, $p < .001$; pointing: Spearman's *rho* = 0.90, $p < .001$), proportion of an action toward the target (looks: Spearman's *rho* = 0.96, $p < .001$; points: Spearman's *rho* = 0.97, $p < .001$), and first action (looks: *Cohen's k* = .75, 87.5% of agreement; points: *Cohen's k* = 1, 100% agreement). Subsequently, statistical analyses were performed on data from the primary coder.

Data Analysis

All statistical analyses reported in this study were two-tailed. Unless otherwise specified, the same general analyses procedures were used in Study 1 and in subsequent studies. The frequentist statistical analyses were performed using R software (v. 4.0.3; R Core Team, 2020). We used non-parametric tests when the data did not fulfill the assumptions of normality. When reported, the Wilcoxon signed-rank effect size refers to the matched rank biserial correlation of the rcompanion package (v. 2.3.27; Mangiafico, 2021). When we found null results, we conducted Bayesian tests with Jasp (v. 0.14.1; JASP Team, 2020), with a Cauchy Prior Distribution set to the default value (.707). When conducting the Bayesian Wilcoxon signed-rank test, we used a data algorithm with five chains of 1000 iterations. We report the Bayes factors expressing support for the null hypothesis over the alternative hypothesis (BF_{01}). Any value of BF_{01} larger than 3 is typically interpreted as meaningful evidence for the null hypothesis.

Results

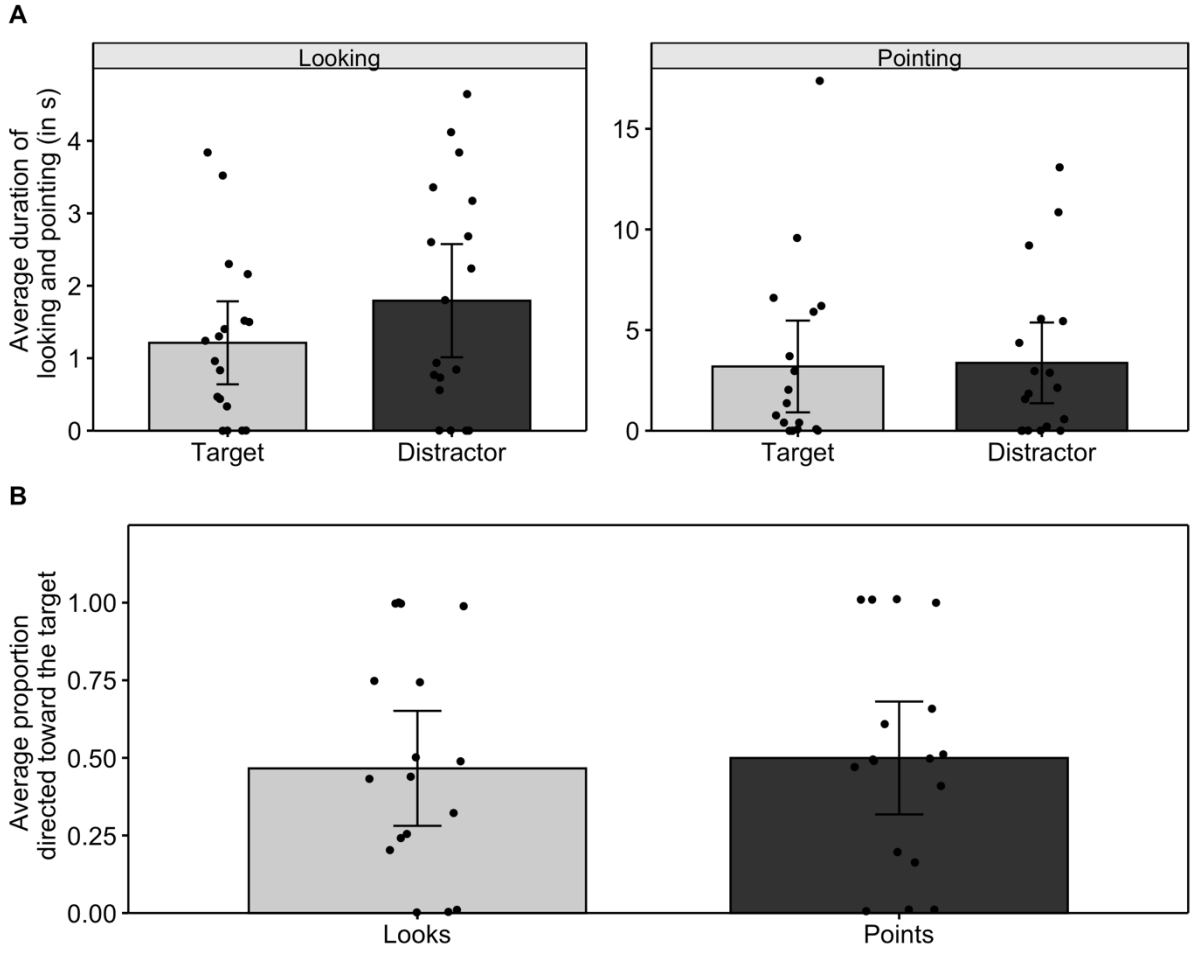
Looks. The participants' first looks were not more likely to be directed toward the target than predicted by chance (7 successes out of 18 – 38.9%; *95% CI* = [17.3, 64.3] $p = .48$, $g = -.11$, binomial test; $BF_{01} = 2.31$, Bayesian binomial test). As Figure S2 panel A shows, the participants did not look longer toward the target ($M = 1.21$ s, $SD = 1.15$) than toward the

distractor (M = 1.79 s, SD = 1.57, Z = 57, p = .23, r = -.33, Wilcoxon signed-rank test; BF_{01} = 2.10, Bayesian Wilcoxon signed-rank test). As Figure S2 panel B shows, the proportion of target looks did not differ from the theoretical value of .5, as predicted by chance (M = .47, SD = .37, Z = 61; p = .73, r = -.10, Wilcoxon signed-rank test; BF_{01} = 3.817, Bayesian Wilcoxon signed-rank test).

Points. During the test phase, the participants were not more likely to point first toward the target than predicted by chance (seven successes out of 17 – 41.2%; *95% CI* = [18.4, 67.1], p = .63, g = -.09, binomial test; BF_{01} = 1.7, Bayesian binomial test). The participants did not point for longer durations toward the target (M = 3.19 s, SD = 4.58, M_{dn} = 1.06 s) than toward the distractor (M = 3.37 s, SD = 4.03, M_{dn} = 1.99 s, Z = 75, p = .96, r = -.02, Wilcoxon signed-rank test; BF_{01} = 4.076, Bayesian Wilcoxon signed-rank test). Moreover, the proportion of target pointing did not differ from the theoretical value of .5, as predicted by chance (M = .50, SD = .35, Z = 46.5; p = .97, r = -.10, Wilcoxon signed-rank test; BF_{01} = 3.793, Bayesian Wilcoxon signed-rank test).

Figure S2.

Results of Pilot S1; Panel A: Average Duration of Looking and Pointing in Seconds per Ball Type (target and distractor); Panel B: Average Proportion of Looks and Points Toward the Target ball.



Note: Error bars represent 95% CI.

Discussion

In Pilot S1, toddlers showed no sensitivity to the experimenter's Socratic ignorance when interpreting her questions. In fact, there was moderate evidence for the null hypothesis for the two most fine-grained measures: the proportion of target looks and the proportion of target points. Thus, Pilot S1 provided no support for the view that early developing representations of Socratic ignorance guide the interpretation of questions (Hypothesis 1). In Studies 1a and 1b, we assessed whether the use of Socratic ignorance to interpret questions

emerges along with changes in the capacity to attribute second-order mental states. Thus, we tested older children (five- to seven-year-olds) because the capacity to attribute second-order mental states, measured by second-order false belief tasks, typically increases between five and seven years of age (Miller, 2009).

Furthermore, in Pilot S1, we did not compare the participants' capacity to use simple knowledge tracking with their capacity to rely on representations of Socratic ignorance. We addressed this issue in Study 1a by testing a first group of participants (five- to seven-year-old children) on a first-order question test in which they could determine the meaning of a request for information by using simple knowledge tracking.

Detailed Scripts for the Second-Order False Belief Tasks used in Studies 1a and 1b

In the second-order false belief tasks, the participants heard stories and they were asked different types of questions: (1) control questions, (2) second-order knowledge questions, and follow-up justification questions and (3) second-order false-belief questions, and follow-up justification questions. When the participants answered incorrectly on one of the control questions, they were corrected, and the experimenter asked the question again, till the participants provided the correct answer.

The participants received no feedback on their answers on the test questions (second-order knowledge questions, false belief questions, and follow-up justifications).

Each participant was tested on the birthday puppy and chocolate bar stories (order of presentation counterbalanced across participants).

Chocolate bar story

Pierre et Emilie are brother and sister. They are in the living room.

Their mother bought a chocolate bar and gives it to Pierre. Emilie doesn't get any chocolate, because she has been naughty.

Pierre eats some of his chocolate and puts the remainder into the drawer. He doesn't give any chocolate to Emilie. Emilie is upset that she does not get any chocolate.

After that, Pierre goes to help his mother in the kitchen. Emilie is alone in the room. Because she is upset, she takes the chocolate from the drawer and puts it into the toy box. While she is putting the chocolate into the toy box, Pierre is passing by the window. He sees that Emilie takes the chocolate out of the drawer and puts it into the toy box. Emilie does not see Pierre.

- Control question 1: Where is the chocolate now ? (correct answer: in the toy box)

- Control question 2: Does Pierre know that Emilie put the chocolate into the toy box ? (correct answer: yes)
- Control question 3: Does Emilie know that Pierre saw her put the chocolate into the toy box ? (correct answer: no)

Now, Pierre comes back to the living room. Kevin wants to eat some of his chocolate. He says, “Hum, I would like to some chocolate”.

- Second-order knowledge question: Does Emilie know that Pierre knows where the chocolate is ? (correct answer: no)
- Second-order knowledge justification follow-up question: Why ?

  Remember, Emilie does not know that Pierre saw her moving the chocolate.
- Second-order false belief question: Where does Emilie think that Pierre will look for the chocolate ? (correct answer: in the drawer)
- Second-order false belief justification follow-up question: Why does she think that ?

Birthday puppy story

Tonight, it’s Louis’s birthday and his mum wants to surprise him with a puppy. She has hidden the puppy in the basement.

Louis says, “Mum, I really hope you got me a puppy for my birthday”.

Because Louis’s mother wants to surprise him with a puppy, instead of telling Louis she got him a puppy, she says “Sorry Louis, I didn’t get you a puppy for your birthday. I got you a really nice ball instead.”

- Control question 1: Did the mother really get a ball for Louis’s birthday ? (correct answer: no)
- Control question 2: What does Louis think that his mom bought for him? (correct answer: a ball)

- Control question 3: Why does Louis's mum say she will get him a ball for his birthday? (correct answer: to surprise him)

Now, Louis, says to his mother: "I am going outside to play." On his way outside, Louis goes down to the basement to fetch his skates. In the basement, Louis finds his birthday puppy. Louis says to himself: "Wow, mum didn't get me a ball; she really got me a puppy for my birthday." His mother does not see that Louis goes down to the basement and finds the birthday puppy.

- Control question 4: Does Louis know that his mother got him a puppy for his birthday? (correct asnwer: yes)
- Control question 5: Does Louis's mum know that he saw the puppy in the basement? (correct answer: no)

Now, the telephone rings, ding-a-ling! Louis's grandmother calls to find out what time the birthday party is. The mother tells grandma on the phone that she got Louis a puppy for his birthday, but that Louis doesn't know this. Then grandma asks mum on the phone, "Does Louis know what you will really get him for this birthday?"

- Second-order knowledge question: What does the mother say to grandma? (correct answer: no)
- Second-order knowledge follow-up justification question: Why does mum say that?Remember the mother does not know that Louis saw what she got him for his birthday.

Then, grandma asks mum on the phone, "What does Louis think you got him for his birthday ? "

- Second-order false belief question: What does the mother say to grandma? (correct answer: a ball)
- Second-order false belief follow-up justification question: Why does mum say that?

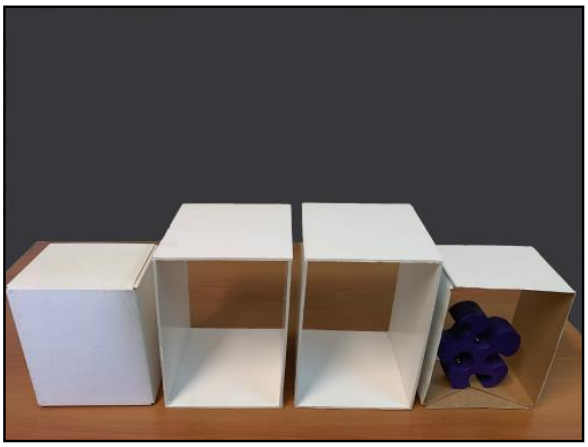
Coding

The participants received a score of 1 for each correct answer on a test question (second-order knowledge and second-order belief questions), and for each correct answer on the corresponding follow-up justification question, thus resulting in a score ranging from 0 to 4 both for second-order knowledge questions, and for second-order false belief questions. The answers to the justification questions were coded following Sullivan et al., 1994's criteria: for each question, the participants received a score of 1 for an appropriate justification (explicit second-order reasoning, implicit second-order reasoning, communicated information or location information) and they received a score of 0 for an inappropriate justification (first-order reasoning, story facts, nonsense or no response).

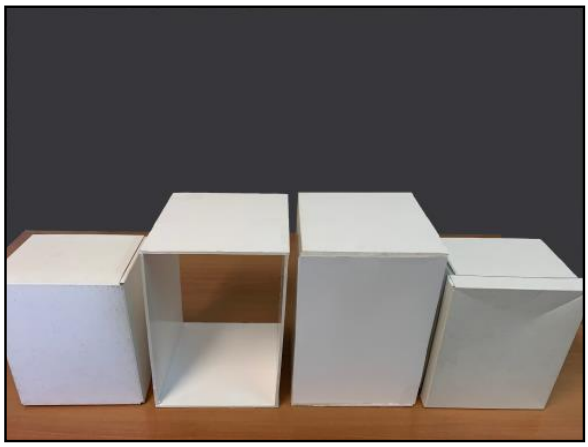
Figure S3.

Pictures of What Was Visible From the Actors' Viewpoint in Studies 1a-4, per Condition

A. 1st Order condition



B. 2nd Order condition



C. Heuristic condition

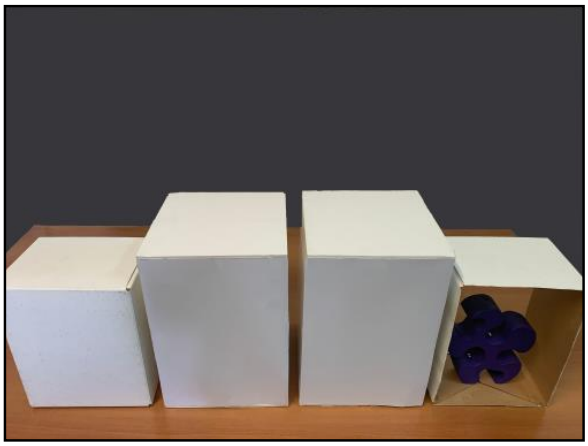


Table S1.

Results of the Linear Models Testing the Effect of the Age (in months, mean centered), Second-Order Knowledge Score, Second-Order False Belief Score and Study on the Eye-tracking Test of Studies 1a and 1b.

Eye-tracking test		Predictors	Estimate	SE	*t*-value	*p*-value	CI 2.5%.	CI 97.5%.
Study 1a	Age model	Intercept	1.02	0.092	11.00			
		Age	0.005	0.008	0.63	.54	-0.012	0.022
	Second-order knowledge model	Intercept	0.81	0.20	3.98			
		Second-order knowledge score	0.074	0.063	1.17	.26	-0.062	0.21
	Second-order false belief model	Intercept	0.90	0.15	6.12			
		Second-order false belief scores	0.057	0.056	1.01	.33	-0.064	0.18
Study 1b	Age model	Intercept	0.78	0.036	21.64			
		Age	-0.004	0.003	-1.53	.13	-0.010	0.001
	Second-order knowledge model	Intercept	0.70	0.079	8.88			
		Second-order knowledge score	0.029	0.027	1.09	.29	-0.024	0.083
	Second-order false belief model	Intercept	0.84	0.065	12.92			
		Second-order false belief scores	-0.029	0.025	-1.71	.25	-0.078	0.021

Table S2.

Results of the Generalized Linear Mixed Models to Test the Effect of the Age (in months, mean centered), Second-order Knowledge Score, Second-Order False Belief Score and Study on the Explicit Identification Test of Studies 1a and 1b.

Explicit identification test		Predictors	Estimate	SE	*z*-value	*p*-value	CI 2.5%.	CI 97.5%.
Study 1a	Age model	Intercept	2.91	1.24	2.35			
		Age	-0.052	0.10	-0.512	.61	-0.36	0.13
	Second-order knowledge model [a]	Intercept	2.67	2.17	3.26			
		Second-order knowledge score	-0.20	0.64	0.11	.74	-3.17	0.83
	Second-order false belief model	Intercept	2.66	1.66	1.60			
		Second-order false belief scores	0.027	0.65	0.04	.97	-1.51	1.60
Study 1b	Age model	Intercept	0.21	0.27	0.79			
		Age	-0.023	0.021	-1.08	.29	-0.065	0.018
	Second-order knowledge model	Intercept	-0.054	0.58	-0.093			
		Second-order knowledge score	0.10	0.20	0.52	.60	-0.29	0.50
	Second-order false belief model	Intercept	0.68	0.50	1.35			
		Second-order false belief scores	-0.21	0.19	-1.11	.27	-0.59	0.15

Note: [a] due to quasi-complete separation of data we used Firth's bias reduction method; we report *Wald's Chi-squared*-values instead of *z*-values for this analysis.

Table S3.

Sample Size Estimation for Study 1b for Comparisons Against Chance Performed with Wilcoxon Signed-rank Tests (eye-tracking experiment), and with Binomial Tests (explicit identification test).

		Children (5- to 7-years-olds)
Estimate of effect size based upon Study 1a	Proportion of looks	d = 0.67
	Explicit identification	g = .44
Estimate of sample size (n required to achieve a power > .9)	Proportion of looks	27
	Explicit identification	12
Power achieved with n = 28	Proportion of looks	.91
	Explicit identification	>.99

Note: The first row reports estimates of effect sizes based upon Study 1a's results. The second row reports estimates of the minimal sample sizes required to achieve a power higher than .90 (*alpha* = .05), assuming effect sizes identical to those computed for Study 1a. Based on these estimates we planned to test 28 participants to achieve sufficient power in all our groups. The third row reports the power achieved by running 28 participants, assuming effect sizes identical to those computed for Study 1a.

Cluster Mass Test Analysis of Studies 1a and 1b

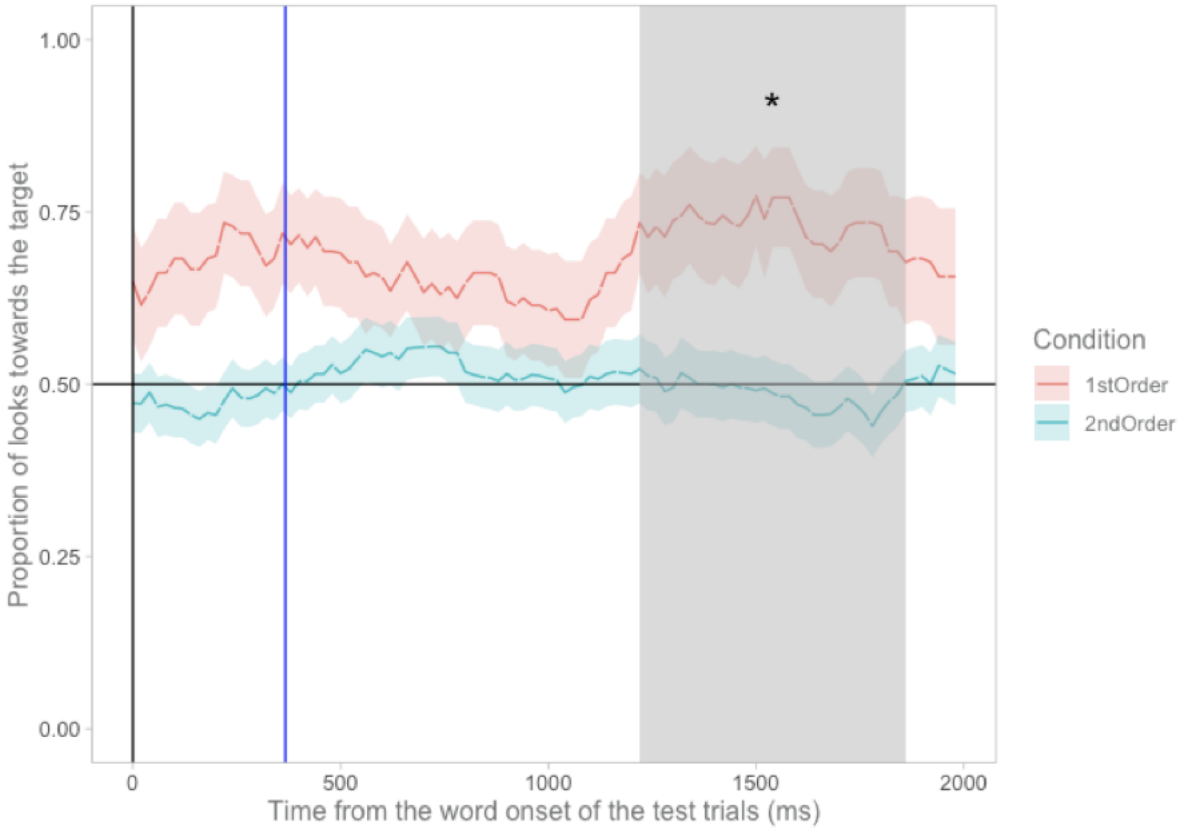
We ran a cluster-based permutation analysis on the proportion of looks towards the target to look for time windows revealing a significant difference between Studies 1a and 1b (for examples of comparable analyses see, Dautriche et al., 2015; de Carvalho et al., 2019; Havron et al., 2019; for a formal presentation of the analysis itself, see Maris & Oostenveld, 2007). This analysis was performed on the whole sample of participants (N = 72), since we observed no effect of Age on performance in the eye-tracking experiment. For each 20 ms time sample, we ran a two-tailed independent t-test on the arcsin-transformed proportion of looks toward the target to test for the effect of Study (Study 1a – first-order ignorance vs. Study 1b – second-order ignorance). Adjacent time samples were grouped in a cluster when their t-value were be greater than a threshold corresponding to a statistically significant difference (t = 2.06). The size of each cluster was measured by computing the sum of all t-values within that cluster. In order to evaluate the probability that a cluster existed by chance, we ran 1000 simulations where condition (Study 1a – first-order ignorance vs. Study 1b – second-order ignorance) was randomly assigned for each test sequence. For each simulation, we computed the size of the largest cluster, just like for the real data (sum of all the t-values within a cluster of significant t-values). Clusters found in the real data were considered meaningful if the probability of observing a cluster of the same size or bigger in the simulations was smaller than 5%, i.e., a threshold equivalent to a p-value of 0.05. This analysis was conducted in R (v. 4.0.3; R Core Team, 2020) using the package eyetrackingR (v. 0.1.8; Dink & Ferguson, 2015).

The cluster-based permutation analysis confirmed that there was a significant effect of Study (1a vs. 1b) on performance in the eye-tracking experiment. As Figure. S4 shows, this effect was distributed in the pre-defined time window, with one time windows where the proportion of looks toward the target object type tended to be different across Studies (1a vs. 1b) (1220-1860 ms: p = .015). Note that in this experiment, there were repeated consecutive

prompt sentences encouraging the participant to look at the target object, both during the familiarization and test phase, thus explaining why, on average, the participants already looked at the target object at word onset in Study 1a (first-order condition).

Figure S4.

Proportion of Looks Toward the Target from the Onset of the Novel Label in Studies 1a and 1b.



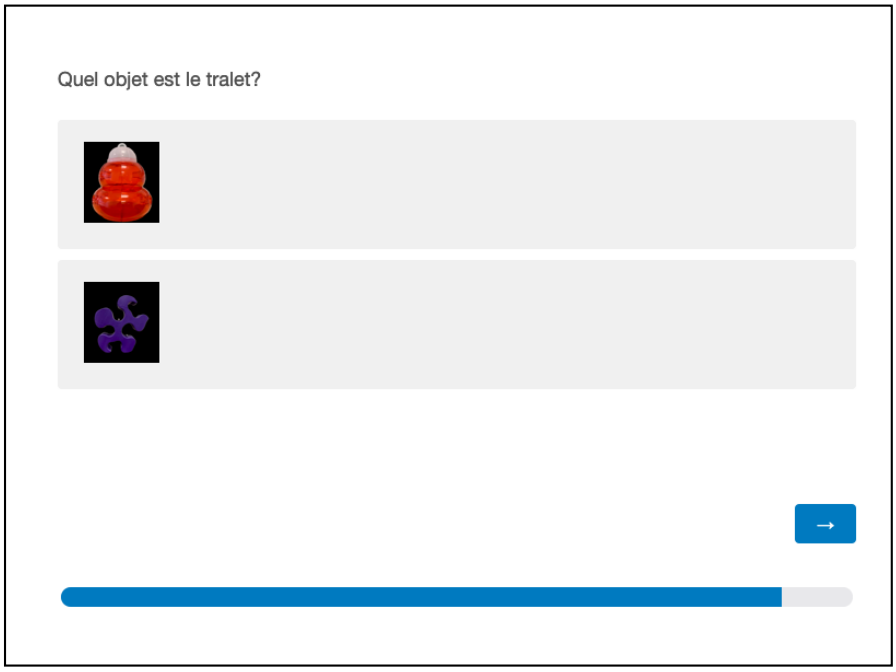
Note: The time-windows goes from 367 ms after the onset of the novel label (blue vertical line) to 2000 ms. Colored shading represents ± 1 SEM. The cluster-based permutation test revealed tendencies for statistical differences (dark grey windows) between the Study 1a (red curve) and Study 1b (blue curve).

*: $p < 0.5$

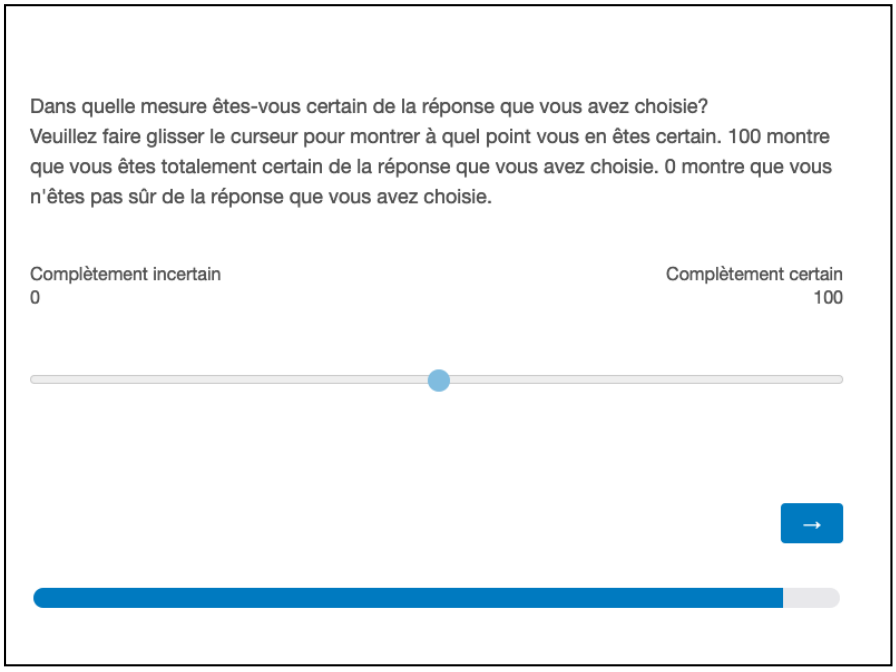
Figure S5.

Screenshots from the test phase of Study 2.

A. Explicit identification test



B. Certainty scale



Note: Panel A illustrates the identification question test. Panel B illustrates the rating of certainty. An English translation of the text in the screenshot can be found in Figure S2.

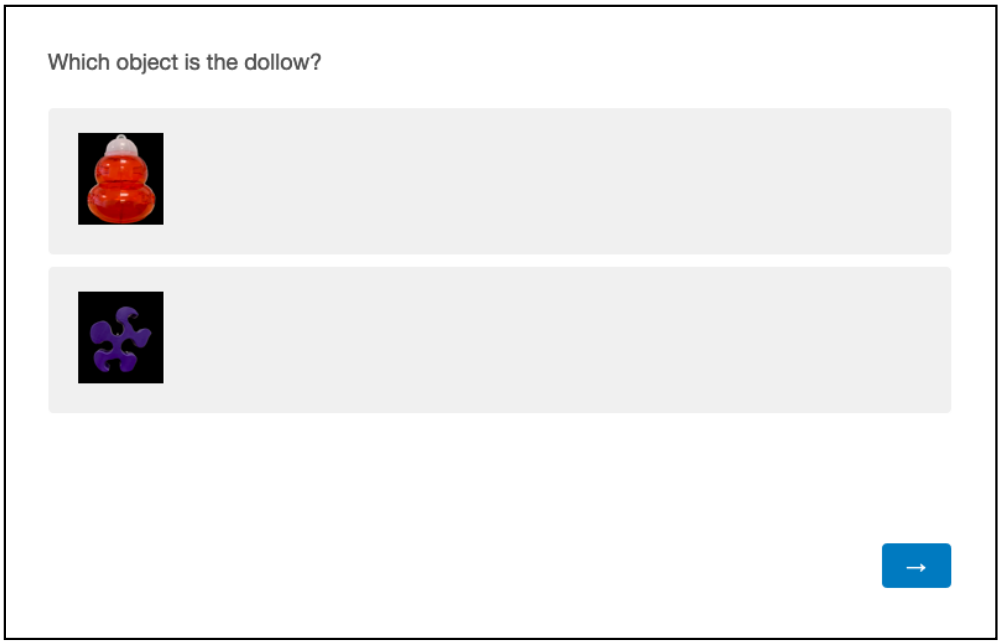
Procedural Details of the Attention Check Question of Studies 2-4

After the experiment, the participants were tested on an attention check question. The screen displayed the following instruction "*Please write in the next question box the color of the object below*", above a picture of the purple wooden unfamiliar object seen in the experiment. Next, the picture disappeared, and a novel instruction appeared "*Based on the previous instructions, write your answer in the box below:*" with a text entry box below in which the participants could type in their answer. The answers "purple" and/or "blue" were coded as correct. The participants who failed on the attention check question were excluded from analysis.

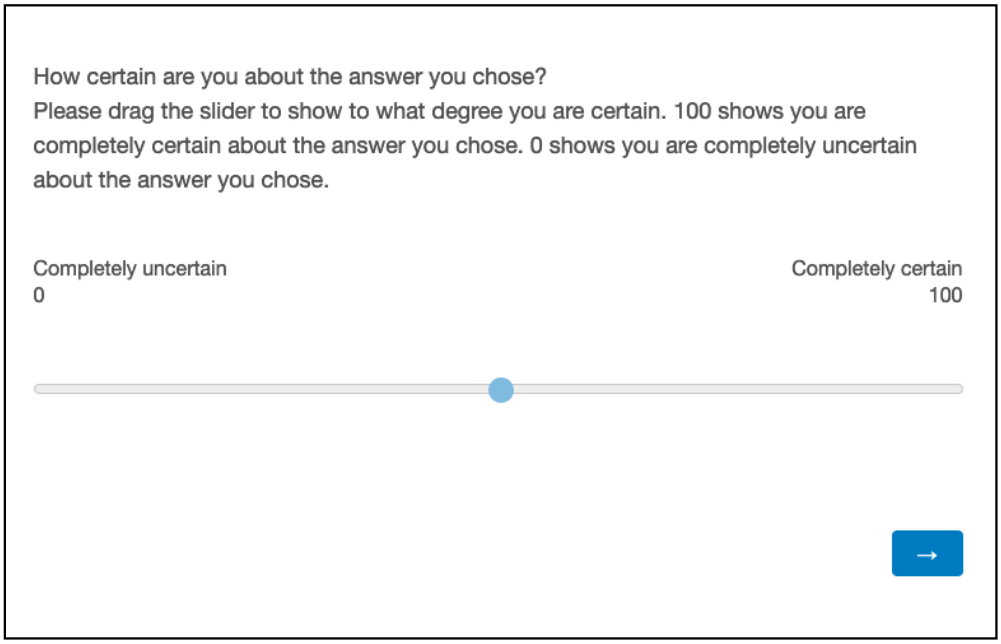
Figure S6.

Screenshots from the test phase of Study 3.

A. Explicit identification test



B. Certainty scale



Note: Panel A illustrates the identification question test. Panel B illustrates the rating of certainty.

References

Dautriche, I., Swingley, D., & Christophe, A. (2015). Learning novel phonological neighbors : Syntactic category matters. *Cognition*, *143*, 77-86. https://doi.org/10.1016/j.cognition.2015.06.003

de Carvalho, A., Babineau, M., Trueswell, J. C., Waxman, S. R., & Christophe, A. (2019). Studying the Real-Time Interpretation of Novel Noun and Verb Meanings in Young Children. *Frontiers in Psychology*, *10*, 274. https://doi.org/10.3389/fpsyg.2019.00274

Dink, J. W., & Ferguson, B. (2015). *EyetrackingR: An R Library for Eye-tracking Data Analysis*. http://www.eyetrackingr.com.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3 : A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175-191. https://doi.org/10.3758/BF03193146

Havron, N., de Carvalho, A., Fiévet, A.-C., & Christophe, A. (2019). Three- to Four-Year-Old Children Rapidly Adapt Their Predictions and Use Them to Learn Novel Word Meanings. *Child Development*, *90*(1), 82-90. https://doi.org/10.1111/cdev.13113

JASP Team. (2020). *JASP (Version 0.14.1)[Computer software]*. https://jasp-stats.org/

Liszkowski, U., Carpenter, M., Striano, T., & Tomasello, M. (2006). 12- and 18-Month-Olds Point to Provide Information for Others. *Journal of Cognition and Development*, *7*(2), 173-187. https://doi.org/10.1207/s15327647jcd0702_2

Mangiafico, S. (2021). *rcompanion : Functions to Support Extension Education Program Evaluation* (R package version 2.3.27) [Computer software]. https://CRAN.R-project.org/package=rcompanion

Maris, E., & Oostenveld, R. (2007). Nonparametric statistical testing of EEG- and MEG-data. *Journal of Neuroscience Methods*, *164*(1), 177-190. https://doi.org/10.1016/j.jneumeth.2007.03.024

Miller, S. A. (2009). Children's understanding of second-order mental states. *Psychological Bulletin*, *135*(5), 749-773. https://doi.org/10.1037/a0016854

Nurmsoo, E., & Bloom, P. (2008). Preschoolers' Perspective Taking in Word Learning : Do They Blindly Follow Eye Gaze? *Psychological Science*, *19*(3), 211-215. https://doi.org/10.1111/j.1467-9280.2008.02069.x

R Core Team. (2020). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Sullivan, K., Zaitchik, D., & Tager-Flusberg, H. (1994). Preschoolers can attribute second-order beliefs. *Developmental Psychology*, *30*(3), 395-402. https://doi.org/10.1037/0012-1649.30.3.395