Infants ask for help when they know they don't know

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Uncertainty monitoring is a core property of metacognition, allowing individuals to adapt their decision-making strategies depending on the state of their knowledge. Although it has been argued that other animals share these metacognitive abilities, only humans seem to possess the ability to explicitly communicate their own uncertainty to others. It remains unknown whether this capacity is present early in development, or whether it emerges later with the ability to verbally report one's own mental states. Here, using a nonverbal memory-monitoring paradigm, we show that 20-month-olds can monitor and report their own uncertainty. Infants had to remember the location of a hidden toy before pointing to indicate where they wanted to recover it. In an experimental group, infants were given the possibility to ask for help through nonverbal communication when they had forgotten the toy location. Compared with a control group in which infants had no other option but to decide by themselves, infants given the opportunity to ask for help used this option strategically to improve their performance. Asking for help was used selectively to avoid making errors and to decline difficult choices. These results demonstrate that infants are able to successfully monitor their own uncertainty and share this information with others to fulfill their goals.

infants | cognition | metacognition | performance monitoring | uncertainty

Humans possess the ability to reflect upon their own knowledge states. This capacity for metacognition allows individuals to acquire new information in an optimal fashion, by flexibly adapting their learning strategies depending on their current state of knowledge (1–3). Accordingly, metacognition has been shown to be an important predictor of learning in adults and school-aged children (4–7). Intriguingly, however, previous research in young children has consistently found strong capacities for learning (8, 9) but poor metacognitive abilities (10–13). For instance, during their first year of life, infants rapidly acquire knowledge by examining their physical and social surroundings. They successfully orient toward aspects of the world that defy their expectations, either by violating the physical principles that they have assimilated (9, 14) or by contradicting their own probabilistic inferences (8). These behaviors indicate that infants can successfully transform the probability of external events into expectations (8, 14). However, children under 4 often fail to provide accurate metacognitive judgments (10–12, 15). Indeed, preschoolers have consistently been shown to experience difficulties in verbalizing their own state of knowledge (10–12). In particular, they tend to overestimate their own knowledge and performance (13, 16, 17). Taken together, these studies suggest that infants learn by exploring their physical and social surroundings but still lack the fundamental ability to reflect upon their own knowledge states.

However, there is increasing evidence that infants engage in self-guided learning strategies that may involve metacognition. For example, infants have been shown to use pointing in an interrogative fashion (18, 19), and have been found to learn better when they are given the opportunity to choose what to learn (20). It might be that these learning strategies rely on purely associative mechanisms, whereby infants adapt to their environment without reflecting upon their own mental states. However, another possibility is that previous studies underestimated self-reflective metacognitive abilities in infants because they focused on verbal reports. Indeed, the ability to talk about mental states only emerges during the third year of life (21). Thus, the poor metacognitive abilities documented previously might simply reflect children's limitations in verbally reporting their own mental states, rather than limitations in metacognition per se. In other words, it is possible that metacognition develops before the ability to verbally communicate one's own mental states.

Interestingly, nonverbal forms of metacognition have been demonstrated in several animal species. For instance, bees, rats, and monkeys have been shown to seek additional information when the available evidence is incomplete, or to defer making a decision when they do not know the best course of action (22–26). These adaptive behaviors demonstrate not only that animals can monitor their own uncertainty (27, 28) but also that metacognitive abilities can be expressed without relying on language. Here we build on this literature to test whether infants can similarly express their uncertainty in a nonverbal manner.

Results

To address this issue, we combined a nonverbal memory-monitoring paradigm developed for rhesus monkeys (22) with a pointing paradigm suitable for human infants. Twenty-month-old infants ($n = 80$) had to remember the location of a hidden toy for a variable delay before pointing to indicate where they wanted to recover it (Fig. 1*A*). Task difficulty was manipulated along two orthogonal dimensions: (*i*) Infants had to memorize the location of the toy for a variable delay (3, 6, 9, or 12 s), and (*ii*) they either saw the toy being hidden at a given location (possible trials) or could not see where the toy was being hidden (impossible trials). Crucially, half of the participants were given the possibility to avoid responding by asking their caregiver for help (AFH) instead of pointing (experimental group; $n = 40$), whereas the other half

Significance

Although many animals have been shown to monitor their own uncertainty, only humans seem to have the ability to explicitly communicate their uncertainty to others. It remains unknown whether this ability is present early in development, or whether it only emerges later alongside language development. Here, using a nonverbal memory-monitoring paradigm, we show that infants are able to strategically ask for help to avoid making mistakes. These findings reveal that infants are capable of monitoring and communicating their own uncertainty. We propose that explicit metacognition develops earlier than previously thought, enabling infants to communicate their own uncertainty nonverbally to gain knowledge from others.

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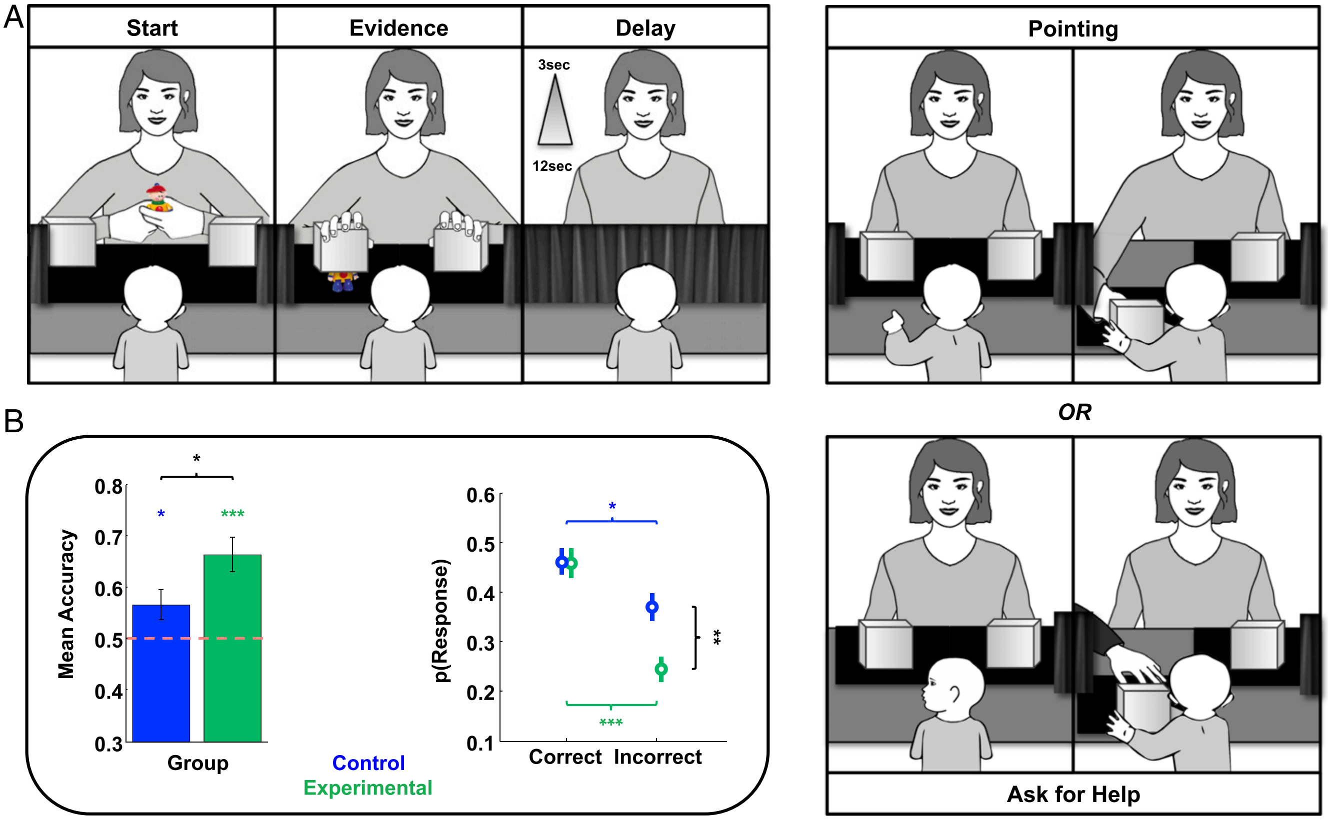

Fig. 1. (*A*) Experimental procedure. Infants watched as a toy was conspicuously hidden under one of two opaque boxes in full view (possible trials) or behind a curtain (impossible trials). For possible trials, the two boxes were then occluded behind the curtain for a variable delay (3, 6, 9, or 12 s). Then, infants were presented with the two boxes again and taught to indicate where they remembered the toy to be by pointing toward its location. The chosen box was then pushed forward for the infant to recover the toy in the case of a correct response, or discover that there was no toy in the case of an incorrect response. Crucially, in a training phase, infants in the experimental group were familiarized with the option of asking their caregiver for help (*Materials and Methods*). By contrast, infants in the control group were not taught the AFH option. Thus, during the rest of the experiment, infants in the experimental group had the opportunity to decide whether they should respond by themselves (i.e., point toward one of the boxes) or acknowledge uncertainty (i.e., ask their caregiver to provide them with the forgotten information), whereas infants in the control group had no other option but to answer by themselves. (*B*, *Left*) Mean accuracy of the pointing responses [i.e., correct responses/(correct + incorrect responses)] for each group (control group in blue and experimental group in green). The red dotted line illustrates chance level. (*B*, *Right*) The proportion of correct and incorrect responses was computed for each participant by dividing the number of correct/incorrect pointing responses by the total number of trials {i.e., [correct trials/(correct trials + incorrect trials + no response trials + AFH trials in the experimental group)] versus [incorrect trials/(correct trials + incorrect trials + no response trials + AFH trials in the experimental group)]}. *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$. All error bars indicate SEMs.

were not given this opportunity and could only choose a location by themselves (control group; $n = 40$). This manipulation enabled us to test whether infants can monitor and communicate their own uncertainty. Indeed, if infants can monitor their own knowledge state, they should use the AFH option (i.e., opt-out) when they have forgotten the toy location, thereby avoiding mistakes and improving their performance (22, 23). Furthermore, if infants can monitor the strength of their memory trace, they should use the AFH option more often at higher levels of uncertainty (i.e., for longer delays and impossible trials).

We first examined the overall performance by computing mean accuracy for the pointing task (Fig. 1*B*, *Left*). Infants pointed more often toward the correct location [mean accuracy 61%; $t(77) = 4.91$; $P < 0.001$; two infants asked for help on every trial and did not provide any pointing response; consequently, they were excluded from all further analysis]. This was the case for both the experimental group [mean accuracy 66%; $t(37) = 4.80$; $P < 0.001$] and the control group [mean accuracy 56%; $t(39) = 2.20$; $P < 0.05$]. Crucially, consistent with our hypothesis, the experimental group performed better than the control group [Fig. 1*B*; $t(76) = 2.21$; $P = 0.03$; see also Fig. S1 for the distribution of this effect]. These results suggest that infants used the AFH option strategically to improve their performance.

However, it remains possible that infants in the experimental group performed better because of a general increase in motivation. In particular, the procedure may have been more stimulating for infants in the experimental group, as they could interact with their parent. Notably, if the effect was due to a general increase in motivation, we should observe a higher rate of correct responses in the experimental group compared with the control group. By contrast, if infants genuinely monitor their own uncertainty, they should specifically ask for help to avoid making mistakes. In this case, we should observe a lower rate of incorrect responses and a similar rate of correct responses in the experimental group compared with the control group. To disentangle these two hypotheses, we thus examined whether the presence of the AFH option in the experimental group led to an increase in the rate of correct responses or to a decrease in the rate of incorrect responses compared with the control group. To do this, we computed separately the proportion of correct responses over the total number of trials and the proportion of incorrect responses over the total number of trials (i.e., see the formula in the legend for Fig. 1*B*). Crucially, this analysis revealed that the performance improvement in the experimental group was primarily due to infants producing a lower rate of incorrect responses compared with infants in the control group [$t(76) = 3.4$; $P < 0.01$], whereas the proportion of correct responses remained equivalent across the two groups [$t(76) = 0.07$; $P > 0.9$]. This interaction between group and response accuracy [$F(1,76) = 4.6$; $P < 0.04$] shows that infants in the experimental group selectively asked for help to avoid making incorrect responses.

The analysis above compared infants familiarized with the AFH option with infants who were not given this opportunity. However, a closer inspection of the individual data in the experimental group revealed important interindividual differences in the use of the AFH option. Indeed, a total of 14 infants out of 40 never asked for help. Importantly, these infants performed at an accuracy rate (56%) that was similar to the control group [56%; $t(52) = 0.01$; $P > 0.9$] and worse than infants who asked for help in the experimental group [72%; $t(36) = 2.33$; $P < 0.03$] (Fig. S2). Likewise, infants who belonged to the experimental group but never asked for help displayed the same rate of correct and incorrect responses as the control group (all $t < 1$; Fig. S2). This observation confirms that infants who asked for help in the experimental group used this option to avoid making mistakes.

We then tested whether task difficulty had an impact on the probability of asking for help. Indeed, if infants were monitoring their own uncertainty about the toy location, they should have asked for help more often as the memorization delay increased. This analysis was restricted to the participants in the experimental group, who asked for help in at least one trial per condition ($n = 21$). An ANOVA revealed that the probability of asking for help was higher for impossible than for possible trials [Fig. 2*A*; $F(1,20) = 24.22$; $P < 0.001$]. Furthermore, within possible trials, the probability of producing an AFH response increased with increasing delays [Fig. 2*B*; $F(1,20) = 4.62$; $P < 0.05$]. Thus, infants' tendency to ask for help varied with task difficulty, suggesting that infants used the AFH option strategically to avoid responding when they felt uncertain about the toy location.

We next considered the possibility that infants simply learned during the training phase to avoid impossible trials by asking for help (*Materials and Methods*). If this was the case, the group differences we observed should be restricted to impossible trials, and both groups should perform similarly on possible trials. By contrast, if infants genuinely monitor their uncertainty, they should be able to generalize the AFH strategy to possible trials and increase their performance accordingly. To test this, we computed mean accuracy for possible trials in isolation. This analysis revealed that even when restricting our analysis to possible trials, performance was higher in the experimental group compared with the control group [69% versus 57%; $t(76) = 2.43$; $P < 0.02$]. This indicates that infants did not simply avoid impossible trials but rather generalized the use of the AFH option to possible trials to improve their performance.

Finally, we examined the proportion of correct and incorrect responses over the total number of trials, computed separately for the possible and impossible conditions (Fig. 2*C*). We performed a mixed linear regression on the proportion of responses, using group, accuracy, and task difficulty (possible vs. impossible) as predictors and subject as a random variable. Critically, we observed a three-way interaction (likelihood ratio tests for model comparison: $N_{\text{subjects}} = 78$, $N_{\text{observations}} = 294$, $\chi^2 = 4.45$, $P < 0.04$), reflecting the fact that there was an interaction between accuracy and group for the possible trials (post hoc regression: $N_{\text{subjects}} = 78$, $N_{\text{observations}} = 156$, $\chi^2 = 8.94$, $P < 0.01$) but not for impossible trials ($P > 0.4$). In the impossible condition, only a main effect of group was observed ($N_{\text{subjects}} = 69$, $N_{\text{observations}} = 138$, $\chi^2 = 5.08$, $P < 0.03$). This pattern was due to the fact that infants in the experimental group avoided impossible trials regardless of accuracy. By contrast, the pattern in the possible condition reflected the fact that the experimental group produced fewer errors than the control group [$t(76) = 3.34$; $P < 0.01$], whereas the proportion of correct responses did not vary across the two groups [$t(76) = 1.04$; $P > 0.3$]. These results confirm that infants used the AFH option strategically to avoid making errors even in possible trials.

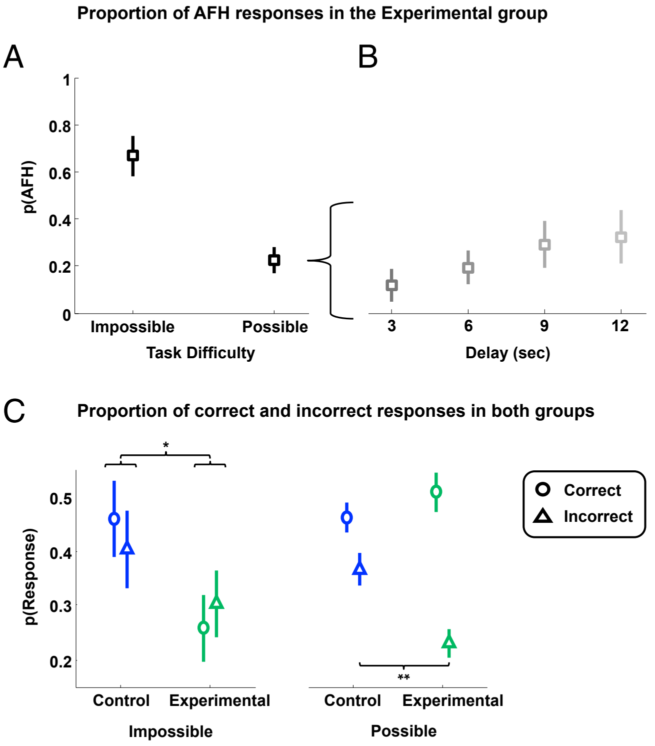

Fig. 2. (*A*) Proportion of AFH responses (i.e., number of AFH trials per number of AFH trials + correct trials + incorrect trials + no response trials) for the possible and impossible conditions in the experimental group. (*B*) Proportion of AFH responses within the possible condition, depending on delay, in the experimental group. (*C*) Proportion of correct and incorrect responses for each group, computed separately for the possible (*Right*) and impossible (*Left*) conditions. *$P < 0.05$; **$P < 0.01$. All error bars indicate SEMs.

Discussion

When given the opportunity to decide whether they should respond by themselves or avoid responding by asking for help, 20-mo-olds are able to strategically adapt their behavior. That is, they selectively seek help to avoid making errors and to avoid difficult choices. In the comparative literature, these adaptive "opt-out" behaviors have been taken as evidence for metacognitive uncertainty monitoring in several species (22, 23, 27). However, some authors have argued that such behavioral patterns could also be explained by associative or reinforcement learning mechanisms (29, 30). For instance, they suggest that difficult trials are simply avoided because individuals learn that the probability of obtaining a reward is lower for those trials (29, 30). Whether or not this associative interpretation can be ruled out in comparative research, in which animals are extensively trained, remains a controversial issue (23, 31). However, in the present study, an associative account seems unwarranted because infants only received a few trials (i.e., a maximum of two trials for each level of task difficulty), leaving little room for associative learning. Moreover, the proportion of AFH responses did not increase across time [effect of trial rank on the proportion of AFH responses: $F(1,20) = 0.22$; $P > 0.6$], ruling out an associative interpretation in terms of reinforcement learning.

Another issue raised in the comparative literature concerns the fact that when the opt-out alternative is available simultaneously with another choice, some competition might take place between these options (28). This might eventually lead to the opt-out option being triggered by default whenever the participant is unable to accumulate enough evidence and commit to a decision before a deadline has been reached. Under this account, infants in our study would simply ask for help by default when no memory is available to trigger an appropriate motor plan. However, if infants simply turned to their parents automatically when no response came to their mind (e.g., to seek comfort), we should observe a similar tendency in the control group. In fact, although infants in the control group were not taught that they could ask for help, and even though their caregiver remained unresponsive, we did observe a few spontaneous "AFH-like" responses in this group [mean number of AFH responses in the control group: 0.6; in the experimental group: 1.42; $t(39) = 3$; $P < 0.005$; Fig. S3]. However, when we analyzed the frequency at which infants looked toward the parent in the control group, we found absolutely no increase with task difficulty (Fig. S3*A*), and excluding those trials did not impact performance (Fig. S3*B*). Thus, infants in the control group did not orient selectively toward their parents when they were more likely to have forgotten the toy location. In turn, this finding confirms that infants in the experimental group did not automatically turn toward their parents when no response came to their mind. Rather, our results are consistent with the idea that infants in the experimental group learned that they could communicate with their caregiver to obtain some help whenever they felt that they were likely to make an error.

The fact that the infants in the control group did not spontaneously ask for help when they were uncertain indicates that they needed to be instructed that the AFH option was available in order for them to use it in a strategic manner. Still, 35% of the infants in the experimental group did not take advantage of the AFH option. This raises the question as to why some infants ask for help whereas others do not. One possibility is that this difference in behavior reflects differences in metacognitive ability. Notably, children have often been found to overestimate their own performances (10, 12, 13). Thus, one tempting interpretation is that some infants never asked for help because they always felt confident that they could respond correctly on their own. However, several alternative interpretations remain. In particular, we noticed that the infants who did not ask for help in the experimental group tended to be less proficient with language, showing smaller vocabulary size compared with infants who did ask for help [nonsignificant trend: $t(35) = 1.59$; $P = 0.12$]. Although this might suggest a link between language acquisition and the emergence of uncertainty monitoring, this effect could equally be due to differential levels of task comprehension. It might also be that other factors, such as executive functions and parental attachment, determined whether or not infants would ask for help in this experiment. Thus, an important avenue for further research will be to investigate interindividual differences in metacognitive abilities and help-seeking behaviors.

Our study reveals that infants have the capacity to monitor their own uncertainty and share it with their caregiver. The fact that infants can communicate metacognitive information to others suggests that they consciously experience their own uncertainty. Indeed, it is generally assumed that to be communicated, even in a nonverbal fashion, representations must be consciously accessed (32–34). In this sense, our results not only provide evidence that infants can form metacognitive representations but also that they can consciously access them (33).

Although several animal species have been shown to monitor their own uncertainty and use this information to regulate behavior (27, 28), only humans are able to explicitly communicate these metacognitive representations to others (i.e., explicit metacognition) (33). This raises the question as to why this ability develops in human beings. An interesting possibility is that explicit metacognition emerges during early development because infants need to communicate their uncertainty to knowledgeable adults (35). This would allow infants to gain relevant information when they estimate that their state of knowledge is insufficient. Relatedly, Shea and colleagues recently proposed that explicit metacognition evolved in humans specifically to broadcast metacognitive representations between agents and allow efficient cooperation (33). In light of our present results, we suggest that explicit metacognition is useful not only for cooperation but also for learning from others.

Materials and Methods

Participants. Eighty healthy full-term infants were included in the final analysis (mean age, 20.17 mo; age range, 19–21.06 mo). Half of them participated in the study as the control group ($n = 40$; mean = 20.08 mo; SEM = 0.09; range, 19–20.97 mo; 19 females), and the other half as the experimental group ($n = 40$; mean = 20.26 mo; SEM = 0.09; range, 19.17–21.06 mo; 19 females). An additional 51 infants ($N_{\mathrm{experimental}} = 22$; $N_{\mathrm{control}} = 29$) were tested but not included in the sample because of fussiness (8), procedure error (5), failure to point to the boxes to indicate a choice in the training phase (21), participation in less than two test trials (5), refusal to take part in the experiment (9), or caregiver interference (3). The study was approved by the regional ethical committee for biomedical research (CERES; Conseil d'évaluation éthique pour les recherches en santé) and informed consent was obtained from the parents before the experiment. All infants were given a diploma for taking part in the study. Infants' vocabulary was evaluated with a French adaptation of the MacArthur–Bates Communicative Development Inventory (36), which allowed us to verify that there were no differences in vocabulary size between the two groups [$t(69) = 0.2$; $P > 0.8$; nine questionnaires were not returned].

Materials and Apparatus. The apparatus consisted of two identical boxes (12 × 12 × 13 cm), each placed on a piece of black cardboard (32 × 31.5 cm). Two wooden toys and two cups were dedicated to the warm-up phase. Ten unique plastic characters were dedicated to the experiment. They were stored on a table out of the infants' view and randomly sampled to be presented individually over the course of 4 training trials and 10 experimental trials. In both groups, the infant was seated in a high chair facing the testing table. The experimenter and the parent sat on the other side of the table, opposite the child (Fig. 1*A*). An opaque black curtain (20 × 60 cm) split the table (70 × 60 × 73 cm) in two. Preceding the session, the parent was instructed to keep his or her gaze on the infant and not to interfere with the infant in any way, and to refrain from moving his or her own head and body and from talking during the trials, except when the task required them to do so. The entire scene was recorded from two perspectives, behind the experimenter and behind the infant, to ensure the neutrality of the parent and experimenter.

Procedure. The experiment started with a warm-up phase during which the infant and their caregiver played with the experimenter. As soon as the infant started to feel comfortable, a training phase began. It consisted of four trials, for which the location of the toys was pseudorandomized. In the first two trials, similar in both the experimental and control group, infants saw the experimenter hide a toy under one of two opaque boxes. After a delay during which the boxes were hidden behind a curtain, the experimenter asked them to point to indicate where they remembered the toy to be. As soon as the infant produced a clear response, the selected box was pushed forward to allow him or her to recover the toy. This was followed by two impossible trials in which the toy was hidden beneath one of two opaque boxes out of the infant's view (i.e., behind the curtain). Infants from the experimental group were taught to ask for help when they did not know the location of the toy. To do so, infants' pointing responses in these trials were ignored, and the experimenter turned to the caregivers and asked them if they knew where the toy was. Caregivers were instructed to wait for their child to look at them in the eyes before helping them by pushing the correct box forward and saying "Here it is, look." Importantly, infants from the control group were not taught this option. To match the two groups, their pointing responses were also systematically ignored in these trials. After asking the infant a second time about the location of the toy, the experimenter simply pushed the correct box forward. The testing phase (10 trials) was identical across the two groups and similar to the training phase, except that there were now five levels of difficulty: possible trials with 3, 6, 9, or 12 s of memorization delay, and impossible trials. The order of presentation was pseudorandomized using a Latin square across the 10 conditions (two sides and five levels of difficulty). The same randomization was used in both groups: Infants in the experimental and control groups were thus matched for order of presentation in both phases of the experiment. The side on which the parent sat was also randomized. The experiment stopped after the infant had completed 10 experimental trials (corresponding to the 10 experimental conditions described above) or became too fussy to continue (in which case they did not complete every experimental condition).

Data Collection and Analysis. Responses were coded from video recordings by two independent observers (M.R.M. and a naïve coder), who were blind to the conditions (location of the toy and delay). Four different types of responses were identified: pointing to the left, pointing to the right, asking for help, or no response (i.e., trials for which the infant did not produce a pointing or AFH response). To compute performance, only pointing responses were used: If the infant pointed toward the box under which the toy was hidden, the response was considered correct; if the infant pointed toward the opposite box, the response was considered incorrect. Therefore, AFH responses did not count as a correct or incorrect response and, just like "no response" trials, were not included in the computation of mean accuracy. Notably, the proportion of "no response" trials was not significantly different between the control and experimental groups [$t(76) = 0.5$; $P > 0.60$]. Coders agreed on 570 of the 641 responses collected (88.92%). Trials with discrepancies between the two codings ($n = 71$) were recoded by a third coder (L.G.) blind to the experimental conditions. The naïve coder's data were used for all of the analyses, except for trials with a disagreement between the two main coders, in which data from the third coder were used. The naïve coder also blindly coded parents' and experimenter's behavior, to ensure their neutrality and that no external information was available to influence infants' choices. Trials with experimental errors ($n = 32$) or parental interferences ($n = 4$) were discarded.

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