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Children's Sensitivity to Their Own Relative Ignorance: Handling of Possibilities Under Epistemic and Physical Uncertainty

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Children more frequently specified possibilities correctly when uncertainty resided in the physical world (physical uncertainty) than in their own perspective of ignorance (epistemic uncertainty). In Experiment 1 ($N = 61$), 4- to 6-year-olds marked both doors from which a block might emerge when the outcome was undetermined, but a single door when they knew the block was hidden behind one door. In Experiments 2 ($N = 30$; 5- to 6-year-olds) and 3 ($N = 80$; 5- to 8-year-olds), children placed food in both possible locations when an imaginary pet was yet to occupy one, but in a single location when the pet was already hidden in one. The results have implications for interpretive theory of mind and ''curse of knowledge.''

Adults' and children's handling or mishandling of uncertainty have long been the focus of research. In the adult literature, researchers have made a distinction between uncertainty that arises in the external world (for example about the fall of a die not yet thrown) and uncertainty that resides internally due to ignorance on the part of the observer (for example about the fall of a die that has been thrown but out of the observer's view). The latter is commonly labeled epistemic uncertainty; the former has been given various labels and here we shall use the term physical uncertainty. In the experiments reported here, we compare children's handling of these two types of uncertainty and show that, as for adults, the variable is of psychological importance: Exactly the same probability is treated differently when uncertainty is epistemic rather than physical. In our tasks with children, however, the effect operates in the opposite direction from that found in the adult studies, and we address why.

We begin by summarizing the published research on children's handling of uncertainty, most of which involves procedures giving rise to epistemic rather than physical uncertainty. Then we show how adults respond differently to the two types of uncertainty in tasks unlike those used with children. Finally we set up our predictions for children's handling of the two types of uncertainty in tasks derived from the developmental literature.

Children's Handling of Uncertainty

Children have a well-documented tendency to underestimate the uncertainty arising from limited information in a wide range of circumstances to a much greater extent than adults. The literature on children's understanding of ambiguity highlights changes around 5 – 8 years in children's acceptance of the possibility of alternative interpretations of limited input (e.g., Beal, 1988; Flavell, Speer, Green, & August, 1981; Robinson & Robinson, 1982; Taylor, 1988). Research on children's readiness to make undecidability judgments in reasoning problems gives results consistent with the work on ambiguity (e.g., Braine & Rumain, 1983; Fay & Klahr, 1996; Klahr & Chen, 2003; Piéraut-Le Bonniec, 1980). By around 7 – 8 years many children demonstrate in various ways that they are aware that visual or oral input can be ambiguous, that a viewer or listener could make the wrong interpretation or would not know the correct interpretation, and that two viewers or listeners might legitimately make different interpretations. Younger children, in contrast, tend to make a single interpretation of information that affords more than one interpretation, tend to judge that they or another person knows the true interpretation when a judgment of ''don't know'' would be appropriate, and tend to judge that limited oral or

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visual input tells or shows them enough to identify the correct referent.

On the other hand, 4–5-year-olds are not completely insensitive to the distinction between informative and uninformative or partially informative information: They may hesitate before interpreting limited information (Plummert, 1996); they appropriately revise incorrect interpretations in the light of further clarifying information (Beck & Robinson, 2001).

In all the tasks used in the studies cited above, uncertainty arises only because information is withheld from the participant, information to which he or she could in principle have access to. For example, in Klahr and Chen (2003) the experimenter constructed an object behind a screen so that the child could not see which of several boxes of components was used, and children judged whether they "knew for sure" or could "only guess" which box had been used. Similarly, in referential communication tasks, the speaker has a particular intended meaning in mind and has typically chosen a real referent that is hidden from the child listener (e.g., Apperly & Robinson, 1998). Had participants been allowed to take a different physical perspective, they could have been certain rather than uncertain.

This is true also of Sophian and Somerville's (1988) game devised to study logical reasoning among 4- and 6-year-olds, which was the inspiration for our procedures in the experiments to be reported. In Sophian and Somerville's game, a toy was hidden in one of several possible cups, which were suspended in a rack above the table. The experimenter's hand moved across the cups in various sequences which allowed the child either to infer exactly where the toy was or to narrow down the possibilities to two, three, or four of the cups. The children's task was to place mats on the table, where necessary, to cushion the fall of the toy from the cup. Hence in this procedure, the toy was already in place, the experimenter knew which cup it was in, and it was only the child's particular perspective that gave rise to her uncertainty. The 4-year-olds as a group showed some sensitivity to uncertainty by placing more mats when there were more logically possible locations for the toy, but even the 6-year-olds' performance was quite poor with only a quarter of them doing this reliably.

Studies in which children are subject to physical uncertainty are rare. Gopnik and Rosati's (2001) report of 4–5-year-olds' ability to report reversals of the duck–rabbit ambiguous figure is relevant, although in this case there is no one true reality about which the child is ignorant. In another study in which children were exposed to physical, as opposed to epistemic, uncertainty, Beck, Robinson, Carroll, and Apperly (2006) used a task in which chance determined whether a toy mouse would emerge from one of two possible outlets of a slide. Children placed mats to catch the mouse (as in Sophian & Somerville's task described above), but at the time the child put mats in place it was still undetermined which way the mouse would fall: Uncertainty resided in the physical world and not just in the child's mind. No change of physical perspective could have rendered participants certain rather than uncertain about the outcome. Under these conditions, 3- and 4-year-old children spontaneously put out two mats on around one third of trials and 5- and 6-year-olds did so on two thirds. We cannot validly make a comparison with the very different study by Sophian and Somerville (1988) mentioned above, but the results are at least consistent with the possibility that children find it easier to specify possibilities under conditions of physical than epistemic uncertainty. In the experiments reported below we make comparisons under matched conditions.

Adults' Responses to Epistemic and Physical Uncertainty

We now consider the adult literature in which the two types of uncertainty have been compared by researchers interested in a difference in people's willingness to bet on uncertainties that are objectively identical, and its implications for theories of decision making (e.g., Kahneman & Tversky, 1982). To return to the examples at the beginning, of a die yet to be thrown as contrasted with a die already thrown but hidden, Rothbart and Snyder (1970) asked undergraduates to place bets on their guessed outcome under these two conditions and to indicate their confidence. Participants betting on a prediction (before they had thrown the die) bet more of the 10 pennies they had been given (median 5 pennies), and felt greater confidence in the correctness of their guess, than participants betting on a postdiction (after they had thrown the die, median 3 pennies). Although the probability of success is identical in the two conditions, participants bet more money when uncertainty was physical rather than epistemic. Similarly, Heath and Tversky (1991) found that adults preferred to bet on the rise or fall of a stock from tomorrow's *Wall Street Journal* (physical uncertainty) rather than yesterday's (epistemic uncertainty).

A different comparison was made by Chow and Sarin (2002), who found that participants placed higher bets on which of two apples had more pips when the apples were uncut than when the experimenter had cut them and counted the pips. In this case, according to our definitions, both conditions involved epistemic uncertainty in that reality had been determined when participants placed their bets. However, Chow and Sarin label the condition involving uncut apples as "unknowable," and treat it as similar to physical uncertainty. Interestingly, these authors point out the subjective element in classifying information as unknowable (by anybody) as opposed to unknown by the participant. For example, a lay person might assume that risks of death from certain causes are unknowable, whereas an actuary might know that probabilistic information is available and so might see themselves as relatively ignorant. We come back to this point in the final discussion.

The results summarized above illustrate a robust finding from research into decision making under uncertainty: Adults are less inclined to bet when they are in a position of relative ignorance vis-à-vis what they could know in principle at the time of betting, or vis-à-vis what somebody else knows at that time. They are more inclined to bet when in principle nobody could know the outcome, or when in practice nobody knows it.

Participants are asked to make objectively the same decision under conditions that differ in whether or not participants hold a particular perspective of ignorance. In the case of physical uncertainty, for example when a die is yet to be thrown, at the time participants make their decision, no change in perspective could change their knowledge (other than a temporal shift to a future point in time). Informally, they cannot think "I don't know what the number is" because there currently *is no number.* In this sense, they have no specific perspective as such. In contrast, under epistemic uncertainty, for example the die has been thrown, if participants took a different physical perspective (allowing them to see how the die fell even if nobody else has seen) or a different mental perspective (that of a knowledgeable other who has seen), their uncertainty would be removed. In this respect, participants have a particular perspective of ignorance because there currently *is* a number about which they can be ignorant. Adults' differential responding suggests that they spontaneously represent their own perspective of ignorance vis-à-vis the more knowledgeable perspective of others or vis-à-vis their own possible perspective of knowledge, even when this is completely irrelevant to the task in hand. This raises an interesting developmental question: What might be the course of development of such representation of a perspective of relative ignorance? In other words, what might be the developmental course of differential responding under physical and epistemic uncertainty?

Predictions

We already know from the literature summarized earlier that under epistemic uncertainty, children under about 7 years of age typically make a single interpretation of limited information when it would be more appropriate to hedge their bets. We know very little about how children respond under physical uncertainty. We now outline three different predictions concerning children's handling of physical and epistemic uncertainty. Prediction 1 draws a straightforward parallel from adults' betting higher amounts under physical than epistemic uncertainty: Children will be more inclined to make a single interpretation (place a bet) under physical uncertainty, and more willing to specify possibilities (hedge their bets) under epistemic uncertainty.

However, we must be cautious about drawing this simple parallel with the adult literature. When adults place a high bet on one outcome, their certainty ratings show that they are nevertheless aware of other possibilities (Rothbart & Snyder, 1970). In contrast, the evidence suggests that the representational demands of holding alternative possibilities in mind simultaneously may be too high for younger children (at least with epistemic uncertainty as investigated so far), and therefore they use the representationally less demanding response of making a single interpretation despite having initially noticed the alternative possibilities (e.g., Beal & Flavell, 1982; Carpendale & Chandler, 1996; Chandler, Hallett, & Sokol, 2001; Flavell et al., 1981; Robinson & Apperly, 2001; Robinson & Whittaker, 1987). This line of argument leads to the opposite expectation from Prediction 1. In Prediction 2, if the context encourages children to represent their own perspective of relative ignorance, the cognitive demands of so doing will make them more likely to respond in a representationally less demanding way to uncertainty, namely by making a single interpretation rather than by specifying possibilities. Conversely, when children are in a position of physical uncertainty, with no additional representational demands, they will be more likely to make the demanding response of specifying possibilities rather than making a single interpretation. That is, they will be more likely to specify possibilities under conditions of physical than epistemic uncertainty, because the former is less demanding cognitively.

Yet a third possibility, Prediction 3, is that children aged around 4–8 years will deal no differently with epistemic and physical uncertainty and will be equally inclined or disinclined to specify possibilities in both types of circumstance. Since Piaget (1926) examined children's egocentrism, we have known that children are much less likely than adults to take into account differences between their own and other people's knowledge when it is important to do so. Failure or inability to take into account another person's lesser knowledge appears to play an important role in, for example, children's failure to acknowledge others' false beliefs (e.g., Wimmer & Perner, 1983), in failures to communicate effectively (e.g., Asher & Wigfield, 1981; Whitehurst & Sonneschein, 1981), and in failures to predict what knowledge another person will gain from limited information (e.g., Taylor, 1988). In these false belief and communication tasks, child participants typically ignore the fact that they *know* something *relevant* about which another person is ignorant. In the circumstances we are interested in here, in contrast (when adults unnecessarily represent their perspective of ignorance under epistemic uncertainty), the child is *ignorant* of something, and it is task *irrelevant* whether or not the child's ignorance is shared. Surely we might expect it to be relatively late in development that children spontaneously represent irrelevant knowledge differences? There are good grounds, then, for expecting that differential responding to physical and epistemic uncertainty would be a relatively late development, emerging well after the age of 4–5 years when children come to acknowledge false belief, and probably after 7–8 years when they come to acknowledge different interpretations of ambiguous input.

We tested our predictions using different materials, procedures, and response measures in the three experiments reported below to find out whether a consistent picture emerged. In all three experiments children were asked to specify possibilities under conditions of certainty (a single outcome could be predicted with confidence) and uncertainty (two outcomes were equally likely), both epistemic and physical. As in Sophian and Somerville's (1988) task, and in Beck et al. (2006), children placed a physical marker to indicate the possible outcomes, for example mats to catch a falling block in Experiment 1, or food to keep a hidden pet in good health in Experiments 2 and 3. By asking children to specify possibilities we avoided any superficial bias against admitting "don't know": Children showed what they *did* know on the basis of the limited information available. On the other hand, by asking children to place two physical markers for a single event, we imposed a strict criterion of simultaneous rather than successive consideration of possibilities.

In each experiment we compared children's responses under conditions of physical and epistemic uncertainty. Did they respond differently under the two conditions (contra Prediction 3)? If so, did children show the same direction of difference as adults (Prediction 1) or the opposite (Prediction 2)?

We aimed to minimize any general bias toward guessing when there were two possible outcomes. In Experiment 1, we encouraged (and children enjoyed) successful catching of a block. In Experiments 2 and 3, children risked an imaginary pet going hungry if they guessed which of two containers it might be in. However, if there was any residual general bias toward guessing, then the matching of tasks ensured that this was the same under conditions of epistemic and physical uncertainty.

Experiment 1

We compared children's responses to physical uncertainty (on *unknowable* trials), when it was as yet undetermined which of two outcomes would happen, with their responses to epistemic uncertainty (on *unknown* trials), when the experimenter knew what would happen but the child did not because the relevant clue was hidden from view.

Method

Participants. There were 31 younger children (12 girls) aged 4 years 5 months to 5 years 4 months, M age $= 4$ years 11 months, and 30 older children (14 girls) aged 5 years 5 months to 6 years 4 months, $M = 5$ years 11 months, from an infants' school in Birmingham, UK serving a mixed working and middle-class population from diverse ethnic backgrounds, with children from Caucasian, Asian, African, and Caribbean backgrounds. All participants' English was deemed competent by their teacher for the task. Because of the very simple nature of the task, adults would find it trivially easy to acknowledge both possibilities in the two uncertainty conditions. Thus, no adult group was included.

Materials. We used a cardboard wall approximately 40 cm^2, which bore three vertical stripes colored orange, black, and green. Three doors were cut near the top of the wall, one in each stripe. Behind the doors was a horizontal shelf, wide enough to hold a small plastic building block but invisible when the wall was viewed from the front. In addition we used two trays approximately 10 cm $\times$ 10 cm, lined with cotton wool, each of which could be placed at ground level beneath one of the doors. Two tall stiff paper bags (of the kind used to hold gift wine bottles), one colored orange and green and the other black, were used to hold plastic building blocks. The tall, narrow shape of the bags meant that when the experimenter put an arm in one, neither he nor the child could see which block was being picked. The orange and green bag contained 10 orange and 10 green blocks, and the black bag contained 10 black blocks. Two blue blocks were used for the warm-up trials.

Procedure. Children were shown the wall with the shelf and the doors, and asked to name the colors of the three stripes. The experimenter (D. J. C.) then showed the two bags with their building block contents, and children identified the colors and noted the match between the colors of the bags and their block contents. On warm-up trials, the experimenter took a block out of sight behind one of the doors and then pushed it through the door so that it fell out at the front of the wall. Children were shown how to place a tray beneath the door to catch the block. They were then shown and told that a block always came through the door of matching color, and were explicitly shown and told that when they did not know which of two doors the block was behind, they needed to place two trays to catch the block.

Each child then had four experimental trials, on two of which it was necessary to put out two trays (reality *unknown* and reality *unknowable* trials), and on two of which it was sufficient to put out one tray (*shown* and *black* trials). On *unknowable* trials the experimenter said he was going to pick a block out of the orange and green bag, but before he picked it the child was asked to put out trays to make sure the block was caught. ''Trays'' in the plural was used so that, if anything, we biased children to place two trays rather than a single one. A child who put out only one tray was prompted ''Could it (the block) go anywhere else?'' and was allowed to add or move a tray if she wished. The experimenter then pushed the block through the door and commented that the child had or had not caught it.

On *unknown* trials the procedure was similar, except that the experimenter picked a block from the green and orange bag *before* the child put out trays, looked at the block and placed it on the ledge behind the matching door without letting the child see, and only then asked the child to place trays, with a prompt as on unknowable trials if necessary.

On *shown* and *black* trials it was sufficient to place one tray, since the child could predict exactly which door the block would come through. On shown trials the experimenter said he would take a block from the orange and green bag, did so, and showed it to the child. Then he placed it on the shelf behind the appropriate door. The child was invited to put out trays. On black trials the experimenter said he was going to take a block from the black bag, and asked the child to put out trays *before* he put his arm in the bag. Hence the shown trials were similar to reality unknown in that the block was in place before the child placed trays. The black trials were similar to the reality unknowable trials in that the child placed trays before the block was taken from its bag.

Each child had one trial of each type (unknown, unknowable, shown, black), presented in four predetermined orders. Constraints on the orders were that the pattern of sufficient tray placements was 1, 2, 2, 1 or 2, 1, 1, 2. The four orders were: unknowable, black, shown, unknown; unknown, shown, black, unknowable; shown, unknowable, unknown, black; black, unknown, unknowable, shown.

Results and Discussion

On each trial children received a score of 1 if they spontaneously put out the sufficient number of trays in the correct location (1 on shown and black trials, 2 on unknown and unknowable trials), and a score of 0 if they did not (strict coding).

A second, lenient scoring system included responses following any prompt on determined and undetermined trials: Children gained a score of 1 if they passed under the strict coding above, or if they added a second tray appropriately after the prompt so that both doors were then covered.

To check for effects of trial order while having sufficient numbers in each cell to identify any such effects, we compared scores for children who began with an unknowable trial with scores for children who began with an unknown trial. No significant or near-significant effects were found. Trial order was therefore ignored in subsequent analyses.

We began by examining performance across the four types of trial to judge whether children treated the game as intended. In this and subsequent experiments, alpha was set at .05 and thus all results reported as significant are $p < .05$ or better.

As shown in Table 1, children nearly always put out only one tray (gaining a pass) on shown trials (certainty) when that was sufficient, because they had seen the orange or green block before it was placed on the shelf behind the matching door. On black trials (certainty), when the child had not seen the block but could infer that it was black, there were 10 occasions when the child placed a tray under the black door and unnecessarily but not wrongly placed

Table 1
Experiment 1: Frequency of Pass and Fail Responses By Age Group and Trial Type

	Performance strict coding (lenient coding, where included, in brackets)	
	Fail	Pass
4–5 years ($N = 31$)		
Unknowable	11 (1)	20 (30)
Unknown	19 (8)	12 (23)
Black	7	24
Shown	1	30
5–6 years ($N = 30$)		
Unknowable	4 (2)	26 (28)
Unknown	17 (9)	13 (21)
Black	4	26
Shown	1	29

a second tray under another door (perhaps because they were invited to place ''trays'' rather than ''a tray''). On one trial a child wrongly failed to place a tray under the black door. Despite these responses, and despite the biasing prompt, on the great majority of trials children placed only one tray when that was sufficient to ensure that they caught the block.

We can therefore go on to examine performance on trials when one tray was not sufficient: unknown and unknowable trials. On both these trial types the child knew only that the block was either orange or green. On unknowable trials the particular block was yet to be chosen when the child placed trays, and on unknown trials the block was already in place on the shelf but hidden from the child. We compared performance on these trials using McNemar tests. Using the strict coding, nine 4–5-year-olds passed the unknowable trial but not the unknown trial, and 1 showed the opposite pattern. This difference was significant, $N = 31$. The same significant difference was found for the 5–6-year-olds: 14 children passed unknowable but not unknown and 1 showed the opposite pattern, $N = 30$. The difference between trials remained for the younger group when the liberal coding was used, 7 children passed unknowable but not unknown, none showed the opposite pattern, $N = 31$, but failed to reach significance for the older group, although the pattern was the same. Nine children passed unknowable and not unknown, 2 showed the opposite pattern, $N = 30$, *ns*. Age differences were not significant: Children in both age groups showed good performance on the unknowable trials, but performed relatively poorly on the unknown trials.

Children more readily realized that one tray was insufficient when a block was yet to be selected than when one was already in place behind one of the doors. Even the 4–5-year-olds were able to cover both possibilities on unknowable trials, but even 5–6-year-olds often failed to do so on unknown trials. We checked that children who wrongly put out only one tray on unknown trials were not able to work out behind which door the experimenter had placed the block: They placed the tray under the correct door on 52% of occasions, and under the incorrect door on 48% of occasions.

The better performance on unknowable (physical uncertainty) than unknown trials (epistemic uncertainty) goes against Predictions 1 and 3, but is in line with Prediction 2. According to Prediction 2, children this age do spontaneously represent their own position of ignorance under conditions of epistemic uncertainty; this is representationally demanding for them, and therefore they use a less mature response of making a single interpretation. Under conditions of physical uncertainty there are no additional representational demands and children can acknowledge both possibilities.

Experiment 2

In this experiment we again investigated children's willingness to acknowledge simultaneously two possible outcomes of a single event, but this time the children acted on behalf of a protagonist who shared their own state of ignorance. One possibility is that in Experiment 1, even though children did not have to make a ''don't know'' judgment, under epistemic uncertainty they were unwilling to admit their own relative ignorance by placing two physical markers for a single event. If so, acting on behalf of somebody else should minimize any bias of this kind. In addition, in Experiment 2, unlike Experiment 1, the experimenter appeared to share the child's position of ignorance under epistemic uncertainty as well as under physical uncertainty.

We again compared children's judgments under two conditions. In one, similar to the reality unknown trials in Experiment 1, the event in question had already happened: An imaginary pet was in one of two boxes but neither child nor story protagonist knew which. In the second condition, similar to the reality unknowable trials in Experiment 1, the event in question was yet to happen: An imaginary pet was not yet in either box. We were interested in whether, in line with Prediction 2 and the results of

Experiment 1, children found it more difficult to acknowledge the two possibilities when the pet already occupied one of the boxes (epistemic uncertainty) than when it was not yet in place (physical uncertainty).

Method

The experimenter (M. G. R.) described a scenario about Mr. Jones who works in a pet shop which contains a number of boxes of different colors and sizes for housing and transporting pets. The child's task was to act on behalf of Mr. Jones: placing food in sealed boxes that could contain animals to be transported to another shop, or putting locks on boxes so the animal could not escape. The child always shared the same state of knowledge or ignorance as Mr. Jones.

Participants. We included children similar in age to the older age group in Experiment 1: 30 children (18 girls) aged 5 years 9 months to 6 years 9 months, *M* age = 6 years 2 months. All attended a primary school serving a mixed working and middle-class population in Staffordshire, UK. All were Caucasian and had English as their first language.

Procedure. The experimenter explained the scenario: "This is Mr. Jones and Mr. Jones works in a pet shop. There are lots of boxes in the pet shop that the pet shop owner uses to send animals to other shops. The owner of the pet shop is always working at another shop a long way away so he leaves messages for Mr. Jones telling him what to do. Every week Mr. Jones has to send some animals to the other shop. He also has to send plenty of empty boxes so that the other shop always has somewhere to keep their animals." All children had two experimental trials involving ambiguous messages, one with reality *unknown* and one with reality *unknowable*, with order counterbalanced between children. In addition, all children had two unambiguous control trials in which the message contained sufficient information for them to know the true state of affairs: Reality was known. One of these unambiguous trials used the materials of the unknown task, and the other used the materials of the unknowable task. The unambiguous control trials immediately preceded their matching ambiguous trial in order to give children any benefit of experiencing the contrast between ambiguous and unambiguous messages.

In the *unknown* task the child was shown a set of three boxes, for example one large red box, one large blue box, and one small red box. The experimenter demonstrated the placing of locks on the boxes to make sure an animal did not escape, or the placing of food containers to make sure any animal inside did not go hungry on its journey. The experimenter read out an ambiguous message from the owner, for example "The mouse is in the large box." The experimenter explained the response options, for example putting food in the large red box only, the large blue box only, or both large boxes. Children were then asked "Show me where Mr. Jones will put food to make sure the mouse has food to eat," and to explain their response. The appropriate response was to put food in both possible boxes. After children had responded, they were offered an alternative response: Children who had put food in only one box were asked "What about putting food in both boxes, would that be OK?" Children who spontaneously put food in both boxes were asked whether it was OK to put food in only one. Children who had not already given a clear justification for a correct response were invited again to do so. Finally children were asked to recall what the message was on that trial.

On the matching control trial using the same materials, the message was unambiguous, for example "The hamster is in the blue box." It was sufficient to put food in one box. After the child had responded, the experimenter offered the child an alternative, referring to both boxes. There was a final recall check as for the ambiguous message.

In the *unknowable* task the experimenter explained that customers could bring back unwanted pets. They might bring back a grown-up pet, which could go in any empty box, or a baby pet, which must go in a warm box. The child was shown special boxes for baby birds which contained a perch and a bell, and for baby mice which contained a wheel. These boxes for baby pets could be warmed up in advance by turning on a switch. As on the unknown trials, the experimenter read out an ambiguous message from the owner, which left it unclear whether a baby mouse or a baby bird was going to come: ". . . someone is going to bring back a baby pet." The child was asked "Show me what Mr. Jones will do to make sure there is a warm box ready" and to give a reason. The appropriate action was to put the switches on for both baby pet boxes. As on unknown trials, children were offered an alternative response and invited to accept or reject it with a reason, and finally recalled the message.

On the matching unambiguous control trial using the same materials, the message stated whether a baby mouse or bird was due to be returned; hence it was sufficient to put the switch on for one box of the correct type.

Results and Discussion

Recall of the messages was near ceiling: 2 children made errors on one trial only. Concerning selection of food or locks for the boxes, children were scored as passing an unambiguous control trial if they acted only on the location referred to in the message either spontaneously or after the prompt, and gave an adequate reason which indicated that they knew the content of the message, for example "Because there's a mouse in the box" or "The message said mouse." As expected, children performed well on the unambiguous trials, acting only on the box identified in the message: 7 children out of 30 made one or more errors, in every case by responding to two boxes (e.g., large yellow and large green) rather than just the one referred to (yellow). This response is not strictly wrong given the scenario, since there was no penalty for playing safe and covering additional possibilities. Nevertheless, interpretation of the results depends on the majority of children not playing safe when the message was unambiguous, as was the case.

Children were scored as passing an ambiguous experimental trial (whether in the unknown or the unknowable task) if they acted on both possible locations either spontaneously or after the prompt, and gave an adequate reason (either before or after the prompt) which referred to the fact that the animal could be in either location, such as "We don't know which one it's in." Hence the scoring in this experiment was similar to the lenient scoring in Experiment 1, except that children had the additional demand of giving an adequate justification of their response. Eleven children passed both the unknown and the unknowable tasks, 8 failed both, 10 passed only the unknowable task, and 1 child passed only the unknown task. Children who passed only one task were significantly more likely to pass the unknowable than the unknown task (binomial test). As in Experiment 1, children found it easier to acknowledge both possibilities simultaneously when the event was yet to happen compared with when the event had already happened but was unknown to the child.

Results are again in line with Prediction 2 and against Predictions 1 and 3. Here we extend the finding to children's acting on behalf of a story protagonist (thereby avoiding any unwillingness to admit their own ignorance), to circumstances when the child's ignorance was apparently shared by the experimenter, and to conditions under which they were expected to give a verbal justification of their response rather than just respond appropriately.

One possible weakness of the procedure in Experiment 2 is that the unknown and unknowable tasks did not use the same materials, and it could be that, for some reason, children just found it more inviting to switch on both switches for a baby pet of unknown identity than to place food in both boxes for a pet in an unknown location. This seems unlikely, particularly given the high frequency of selecting a single switch on unambiguous trials using the materials of the unknowable task. Nevertheless, as a further check in Experiment 3 we created a very close match between reality unknown and unknowable tasks: Only the tense of the verb in Mr. Jones' message differed.

In addition, in Experiment 3 we changed the response measure again to explore the generality of the difference in difficulty between unknown and unknowable conditions. In Experiment 1 children acted on their own behalf; in Experiment 2 children acted on behalf of a protagonist who shared their own perspective of ignorance; in Experiment 3 children gave a mental state judgment for the protagonist (who shared their perspective of ignorance) by indicating what Mr. Jones *knew* about where the pet was.

Experiment 3

In the final experiment we used the same pet shop scenario as in Experiment 2, but we included trials on which children were asked to make judgments about Jones' knowledge rather than his behavior. For these trials we used a task similar to the reality unknown task of Experiment 2, and created a reality unknowable version. Instead of acting on behalf of Mr. Jones, children selected a thought bubble to indicate what Mr. Jones knew about where the pet was (on reality unknown trials) or what he knew about where the pet would be (on reality unknowable trials). In addition, each child had one ambiguous reality unknown trial exactly the same as in Experiment 2's reality unknown task, with a matching unambiguous control message: We now label these *action* trials to differentiate them from the thought bubble trials. Given the rather poor performance of the 6-year-olds in the reality unknown task in Experiment 2 (40% correct), in Experiment 3 we included an older age group, 7- to 8-year-olds.

The judgments on action trials (as used in Experiment 2) and the new thought bubble trials were importantly different. When the message was ambiguous, children were expected to indicate using a thought bubble that Mr. Jones knew that the pet was *either* in location 1 *or* in location 2, but that his appropriate action was to place food *both* in location 1 *and* in location 2. We cannot assume that children would find it equally easy or difficult to acknowledge the two possibilities in these two different ways, even though the underlying problem was the same. Should the thought bubble judgments prove to be more difficult, we would not expect this to be merely due to superficial task demands: Previous research (Wellman, Hollander, & Schult, 1996) has shown that children very much younger than the participants in this experiment can use thought bubbles, for example, to acknowledge another person's false belief. In addition, the linguistic concept "either . . . or" is one of a group of early acquired linguistic concepts included as sub-test items in The Clinical Evaluation of Language Fundamentals–Preschool Test (CELF–Preschool; Wiig, Secord, & Semel, 1992). In the test, designed to assess receptive and expressive language ability, 3-year-olds are expected to be able to respond correctly to a direction to select a picture of "either A . . . or B." We therefore expected the 5- to 6-year-olds in our sample to have no difficulty selecting thought bubbles to indicate what the protagonist knew, and no difficulty understanding "either . . . or."

Participants. Participants included 40 children (16 girls) aged 5 years 9 months to 6 years 5 months, M age = 6 years 2 months, and 40 children (21 girls) aged 7 years 9 months to 8 years 7 months, $M = 8$ years 1 month. Children attended two primary schools serving a working and middle-class population in Staffordshire, UK. Seventy-eight were Caucasian and 2 were British Asian, and all had English as their first language.

Procedure. Each child had four trials: two action trials (one reality unknown trial and one unambiguous control trial using the same materials), which were exactly the same as in Experiment 2, and two thought bubble trials. Half the children received a thought bubble trial of the reality unknown type, and a matched unambiguous control trial. The other half of the children received a thought bubble trial of the reality unknowable type, and a matched unambiguous control trial. We did not include action unknowable trials (which would have involved the baby bird and baby mouse boxes from Experiment 2) in order to use the same scenario across all trial types: All trials involved the sets of large and small boxes used for the reality unknown trials in Experiment 2.

On the *thought bubble* trials with reality *unknown* and reality *unknowable,* the experimenter (M. G. R.) read out an ambiguous message from Mr. Jones as in Experiment 2. For example, "The rabbit is in the large box" (unknown) or "The rabbit is going to be in the large box" (unknowable) could refer to either the large pink or the large white box. Instead of acting on the boxes, the child was asked to choose one picture from a set of three pictures with thought bubbles to illustrate what Mr. Jones now knew about the pet's location. One picture showed Mr. Jones with a thought bubble containing the large pink box, a second picture showed him with a thought bubble containing the large white box, and a third picture showed him with a thought bubble containing both the pink and the white boxes with the word "OR" between and a large question mark. The experimenter explained what each picture meant, and asked the child to select one and give a reason. As in Experiment 2, children were then offered an alternative response. For example, a child who had chosen the option depicting "either box" was asked "What about choosing the picture that shows he knows the rabbit is in the pink box, would that be OK?" Finally children were asked to recall what the message was on that trial. Unambiguous control trials were similar, referring either to a single current location or to a single future location.

Result and Discussion

As in the previous experiments, alpha was set at .05 and thus all results reported as significant are $p < .05$ or better. As in Experiment 2, recall of the messages was good on all trial types. Performance on unambiguous control trials was also good: On unambiguous action trials two children made errors, and on unambiguous thought bubble trials no child made an error.

In the reality unknown action task we used the same criteria for scoring responses as correct or incorrect as in Experiment 2. Equivalent criteria were used for the thought bubble reality unknown and unknowable trials: Children passed if they selected the dual option thought bubble either spontaneously or after the prompt, and gave a reason which referred to the fact that the pet could be in either location. The results are summarized in Table 2.

On *reality unknown action* trials, 12 out of forty 5–6-year-olds (30%) passed, as did 27 out of 40 (67%)

Table 2
Experiment 3: Frequency of Pass and Fail Responses By Age Group and Task

Task	Age (years)	Fail	Pass
Reality unknown action	5–6 ($N = 40$)	28	12
	7–8 ($N = 40$)	13	27
Reality unknown thought bubble	5–6 ($N = 20$)	17	3
	7–8 ($N = 20$)	11	9
Reality unknowable thought bubble	5–6 ($N = 20$)	18	2
	7–8 ($N = 20$)	4	16

7–8-year-olds. As expected, older children performed significantly better than younger ones, $\chi^2(1; N = 79) = 11.26$, although performance was not at ceiling even among the older children.

On the *reality unknown thought bubble* trials, 3/20 (15%) 5–6-year-olds passed, as did 9/20 (45%) 7–8-year-olds. Although the frequencies of correct responses suggest that performance was poorer than on reality unknown action trials, the difference failed to reach significance: Combining across the age groups, 5 children passed the action trials but failed thought bubble, compared with none who showed the reverse pattern.

On *reality unknowable thought bubble* trials 2/20 (10%) 5–6-year-olds responded correctly, as did 16/20 (80%) 7–8-year-olds. The older children, but not the younger, performed better on the reality unknowable thought bubble trials than on the reality unknown thought bubble trials: $\chi^2(1; N = 39) = 5.23$ (7–8 years); $\chi^2(1; N = 39) = 0.23$, *ns* (5–6 years). This is consistent with the results of Experiments 1 and 2.

The poor performance of the 5–6-year-olds in both the reality unknown and unknowable thought bubble trials suggests that even the unknowable thought bubble judgments were still too difficult for them. As mentioned above, it is unlikely that children this age suffered from superficial difficulty with the thought bubble procedure, or with understanding what "either . . . or" means. A more likely interpretation is that children find it easier to acknowledge *both* possible outcomes of a future event (as in the action task and in Experiments 1 and 2) than to acknowledge that *either* one or the other is or will be the case. For our purposes here, the important result is that for the older children at least, we again find differentiation between reality unknown and unknowable trials, which map onto epistemic and physical uncertainty. As in Experiments 1 and 2, the results are in line with Prediction 2 and against Predictions 1 and 3.

Final Discussion and Conclusions

The results of the three experiments reported here provide evidence only for Prediction 2, that children aged between 4 and 8 years differentiate conditions of epistemic uncertainty from physical uncertainty. Prediction 2 rested on the assumption that the unknown condition encourages representation of one's own perspective of ignorance, which is resource demanding and thus makes it difficult for young children also to meet the representational demands of acknowledging possibilities. Thus, children are more likely to make a single interpretation. This account fits the results with three different response measures: The child's own action (Experiment 1), action on behalf of a story protagonist who shared the child's perspective of ignorance (Experiment 2), and mental state judgments on behalf of a story protagonist (Experiment 3). Differential responding to the two types of uncertainty was apparent even for 4-year-olds in Experiment 1. In the thought bubble task of Experiment 3, children had to indicate that the outcome could be either X or Y instead of marking both X and Y as in Experiments 1 and 2. In Experiment 3, it was only the 7–8-year-olds who differentiated between types of uncertainty. Not surprisingly, the particular task demands are relevant to whether or not children represent their own perspective of ignorance under conditions of epistemic uncertainty.

The procedures used in the three experiments differed not only in the response measures but also in the manner in which epistemic uncertainty was conveyed. In Experiment 1, the game was controlled by the experimenter and on reality unknown trials the experimenter knew which door the block was going to fall through. There was a clear difference in knowledge between child and experimenter. This difference in knowledge might have been sufficient to encourage children to represent their perspective of ignorance, but it was not a necessary feature for them so to do. In Experiments 2 and 3, the child was given no indication that the experimenter knew the location of the imaginary pet; the experimenter's role was simply to read out the messages from the pet shop owner. In this case, epistemic rather than physical uncertainty arose because it was salient that the child *could* easily know which box contained the imaginary pet rather than because somebody else did know. This could also have been the relevant variable in Experiment 1, since the child could have looked behind the doors to see where the block was hidden. Hence the variable common to the epistemic uncertainty conditions across all three experiments was the salient presence of a hidden object (albeit imaginary in Experiments 2 and 3) that the child could have accessed had she taken a different physical perspective. From the results so far, however, we cannot specify the limits of the set of circumstances that prompt children to represent their own perspective of ignorance.

As mentioned in the introduction, there is a subjective element in whether participants treat a particular situation as physical or epistemic uncertainty: One participant might realize that they could know about a particular event and so treat uncertainty as epistemic, whereas another might assume that the same event is unknowable and so treat uncertainty as physical. Procedural details might also be influential. For example, the unknowable conditions in Experiments 2 and 3 could have been construed as unknown, had children assumed that the supposed writer of the ambiguous messages knew their intended meaning. In our procedure the writer (the shop owner) was deliberately a remote figure who lacked salience, but if this feature were changed then children might construe uncertainty as epistemic and so find it more difficult to acknowledge possibilities.

Concerning age-related differences, we do not yet know at what age children begin to show an adult-like preference for making predictions under physical rather than epistemic uncertainty. A prerequisite for showing adult-like prediction preferences is that children can bear in mind both (or all) possible outcomes, and it is this prerequisite acknowledgement of possibilities in which we were interested here. It could be that as soon as children can bear in mind possibilities under both physical and epistemic uncertainty, they prefer to make a prediction under physical uncertainty. This seems unlikely if the procedure involves an explicit comparison between conditions, since to show a consistent prediction preference children would need to be able to meet the additional demands of making such a comparison between the two uncertainty conditions.

Although we explain the results (i.e., children's pattern of results opposite to adults') in terms of children making single interpretations when the representational demands of holding possibilities in mind are too great, another explanation for the results deserves to be considered: Maybe children who acknowledge possibilities correctly under physical uncertainty *could* also do so under epistemic uncertainty, but for some reason choose to guess. This seems plausible. Researchers of children's referential communication skills have pointed out that children may assume that speakers will provide clear, unambiguous messages that permit a single interpretation, and therefore are biased to make such an interpretation (e.g., Ackerman, 1981; Speer, 1984). Similar arguments are made in the literature on children's handling of undecidability (e.g., Acredolo & Horobin, 1987). As pointed out in the introduction, this published research uses epistemic rather than physical uncertainty. Under epistemic uncertainty there *is* a reality that the child might assume is being clearly communicated (in the pet shop task in Experiments 2 and 3) or which they are somehow expected to know (in the doors game in Experiment 1).

With this account we are left with explaining a puzzling switch in development, from a preference for predicting outcomes under epistemic uncertainty in childhood, to preferring to predict under physical uncertainty in adulthood. However, this account suffers from a further problem. The suggestion that under epistemic uncertainty children are particularly inclined to make a single interpretation despite being aware of both possibilities, ignores the argument made by many researchers that children's single interpretations of ambiguous input are not due *only* to a guessing bias. For example, under conditions of epistemic uncertainty as used in the published literature, children younger than around 7 years evaluate the input as adequate (e.g., Beal & Flavell, 1982; Flavell et al., 1981; Robinson & Apperly, 2001; Robinson & Whittaker, 1987). They also fail to explain why different people can make different interpretations of limited input (Carpendale & Chandler, 1996; Chandler et al., 2001). Results such as these support the argument that under epistemic uncertainty children suffer from a genuine inability to handle more than one possible outcome of a single event.

Under our account, there is no developmental switch in preference for predicting outcomes under physical rather than epistemic uncertainty. Rather, the very possibility of processing possibilities in an adult-like manner, and therefore showing adult-like preference, demands an ability not yet available to young children.

There are two main points of interest in our results. First, insofar as children performed more poorly under epistemic uncertainty when there *was* a reality of which they were ignorant, than under physical uncertainty when there was none, our results appear at first sight to have something in common with research showing children's difficulty inhibiting a response to a known reality. This well-documented difficulty has been termed a ''realist bias'' (Mitchell, 1996) or a ''curse of knowledge'' (Birch, 2005; Birch & Bloom, 2003, 2004), and is one from which adults also suffer to a lesser degree (e.g., Birch & Bloom, 2003; Keysar, Barr, Balin, & Brauner, 2000; Keysar & Henly, 2002; Keysar, Lin, & Bar, 2003; Mitchell, Robinson, Isaacs, & Nye, 1996). When children or adults respond with their own knowledge although the task demands that they take the perspective of a more ignorant other, the interpretation is that there has been a failure of perspective taking.

In our tasks, however, a failure of perspective taking would result in no differentiation between physical and epistemic uncertainty: As we argued in the introduction, in physical uncertainty there is no perspective to take. If children failed to take a perspective under epistemic uncertainty, they would treat it as if it were physical uncertainty. Since in our tasks children did differentiate between physical and epistemic uncertainty, our interpretation turns the mainstream account for realist errors on its head. Our suggestion is that children spontaneously represented their task-irrelevant perspective of ignorance under epistemic uncertainty. In our tasks, we suggest, children gave precedence to representing their own task-irrelevant perspective, and as a consequence failed to meet the representational demands of holding in mind both possible locations of the block in Experiment 1 or the pet in Experiments 2 and 3.

This raises the important possibility that the extant interpretation of realist errors is wrong. Realist errors should perhaps not be seen as a failure to take another's perspective. Rather, children as young as 4 years may be *particularly* sensitive to the fact that they have an individual perspective on the world, even when this is task irrelevant. On this account, children who make realist errors (e.g., in judgments about a target person's belief) may have recognized that the target has a different perspective, but when ascribing content to this perspective these children lack the necessary resources to resist interference from their own knowledge.

This suggestion accommodates the finding that under some conditions, perhaps when representational demands are low, even very young children do show sensitivity to knowledge differences (e.g., Baldwin & Moses, 1994; Baldwin et al., 1996; O'Neill & Topolovec, 2001). It is also consistent with the suggestion that the construction of alternative perspectives and the ability to resist interference from one's own perspective are distinct functional and neural processes that can be independently impaired by brain damage (e.g., Apperly, Samson, & Humphreys, 2005; Samson, Apperly, Kathirgamanathan, & Humphreys, 2005).

We must make one proviso, however. In our tasks we have shown sensitivity to the variable of relative ignorance: Children responded *differently* under conditions of epistemic and physical uncertainty. In contrast, research on children's handling of relative knowledge examines their skill at responding *correctly*, for example when speaking to a listener who knows less than they do, or predicting the action of a protagonist who is relatively ignorant. It is quite possible to respond differently under different conditions, showing sensitivity to the variable in question, despite showing a high level of errors in any one condition.

The second main point of interest in our results concerns the finding that under physical uncertainty young children can acknowledge possibilities even though they cannot do so under epistemic uncertainty, the condition almost universally used in the published literature on children's handling of uncertainty. Our results therefore have implications for developmental accounts of understanding about ambiguity and about indeterminacy in logical reasoning (e.g., Apperly & Robinson, 1998; Fay & Klahr, 1996). In particular, the results have potentially important implications for research on children's developing understanding of the mind as an active interpreter of information. It is well documented that although children around the age of 4 years are normally willing to acknowledge false beliefs, it is not until they are several years older that they accept that the very same input can be interpreted differently by different people. For example, in one task used by Carpendale and Chandler (1996), a coin was hidden under one of three blocks, and the child participant heard a message that narrowed the possibilities down to two. Two story protagonists each made one of the possible interpretations, and the child was asked to explain why they made different interpretations. Five- to 6-year-olds had difficulty with this, but by 7–8 years many children accepted the legitimacy of the protagonists' different interpretations and explained them in terms of ambiguity in the message. Success in this kind of task is taken as evidence that the child participant has come to construe the mind as an interpreter of information, and has begun to understand the mark that individual minds can place on incoming information. The evidence suggests that this understanding continues to develop through adolescence and into adulthood, with the adoption of increasingly demanding epistemic stances (Kuhn, 2000).

The tasks used in work on interpretive theory of mind involve epistemic rather than physical uncertainty. In the hidden coin task above, the child participant could easily have known where the coin was hidden; she was in a position of relative ignorance. Our results suggest that under such conditions children find it relatively difficult to represent the possibilities *for themselves*. Poor performance in theory-of-mind research involving such tasks might be due not to a failure to understand the mind as an interpreter, but rather to difficulty holding in mind both possible interpretations. If children were faced with two protagonists who made different interpretations under conditions of physical rather than epistemic uncertainty, they might much more readily explain why this was legitimate. What appears in the literature to be an immature conception of the mind may really arise from children's difficulty representing their own position of ignorance under conditions of epistemic uncertainty.

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