



SHORT REPORT

Learning to recognize uncertainty vs. recognizing uncertainty to learn: Confidence judgments and exploration decisions in preschoolers

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Abstract

During exploration, young children often show an intuitive sensitivity to uncertainty, despite their strong tendency towards overconfidence in their explicit judgments. Here, we examine the development of children's explicit and implicit recognition of uncertainty using the same stimuli. We presented 4- and 5-year-olds with objects that varied in their amount of perceptual occlusion, and assessed their ability to distinguish among them using two types of measures. Experiment 1 used a traditional 3-point confidence scale to examine children's explicit uncertainty judgments. We compared these confidence judgments before and after they observed disconfirming evidence, to assess the impact of this experience on their acknowledgement of uncertainty in later trials. Experiment 2 examined children's exploration preference as a measure of implicit sensitivity to uncertainty. Our results indicate that children intuitively recognize gaps in their knowledge, and that this implicit recognition may be leveraged to support their explicit judgments. Specifically, we found that children's baseline confidence judgments improved significantly following the presentation of disconfirming evidence. Furthermore, when asked to make exploration decisions about the same set of objects, children showed a spontaneous sensitivity to uncertainty, prior to any evidence. Taken together, these results suggest that children's exploration behavior may be used as an early developing measure of uncertainty control and raise the intriguing possibility that the experience of unexpected outcomes may play a role in the development of metacognition.

KEYWORDS

ambiguity, cognitive development, confidence judgments, decision-making, exploration, uncertainty monitoring

1 | INTRODUCTION

Children under 8 years of age have traditionally been described as 'eternal optimists' who tend to express overconfidence in their judgments (Beck et al., 2011; Newman & Wick, 1987). That is, young children often indicate high confidence even when they are likely to be incorrect based on the level of uncertainty present (Roebbers, 2002),

and tend to treat partial knowledge as complete (Rohwer et al., 2012). This apparent insensitivity to uncertainty contrasts with self-directed learning in early childhood, which is guided by a preference for what is uncertain (Liquin & Lombrozo, 2020). Preschoolers preferentially explore where they have incomplete or inconsistent information (e.g., Bonawitz et al., 2012; Legare, 2012; Schulz & Bonawitz, 2007) and act to improve their epistemic status when confronted with ambiguous



data (e.g., Cook et al., 2011; Hembacher et al., 2020; Lapidow & Walker, 2020; Zettersten & Saffran, 2021). This not only demonstrates that children intuitively recognize gaps in their knowledge, but also shows that this recognition can motivate early decision-making.

One explanation for the contrast between these literatures proposes a distinction between children's implicit and explicit awareness of uncertainty (Ghetti et al., 2013). Research from Ghetti and colleagues has shown that an explicit awareness of uncertainty begins to develop during the preschool years (Coughlin et al., 2015; Destan et al., 2014; Hembacher & Ghetti, 2014; Lyons & Ghetti, 2011, 2013). This is initially observed in children's 'uncertainty monitoring'—the introspective process by which a learner considers whether a decision made under unreliable conditions is likely to be correct (Ghetti et al., 2013). This is typically measured by asking children to explicitly report how 'sure' they are about an outcome or judgment, using a scale with two or three fixed-points, corresponding to greater or lesser confidence (Hembacher & Ghetti, 2014; Lyons & Ghetti, 2013). Uncertainty monitoring is indicated when the average confidence rating given for correct judgments is higher than those for incorrect judgments.

These studies have also shown that children's sensitivity to uncertainty can be measured implicitly via 'uncertainty control'—using the output of metacognitive monitoring to regulate and optimize decision-making behavior when feeling uncertain (Ghetti et al., 2013; Koriat & Goldsmith, 1996). This ability is reflected in a variety of behaviors, including self-allocation of study time (Destan et al., 2014), tendency to seek help (Coughlin et al., 2015), and opting-out of judgments (Lyons & Ghetti, 2013). For example, Hembacher and Ghetti (2014) asked children for their explicit confidence ratings about their own recognition judgements for a set of previously studied items. They were also prompted to select a subset of those recognition judgments for the experimenter to check for accuracy. Although 4- and 5-year-olds' average confidence was higher for accurate judgments overall, the subset of judgements they selected to be checked was significantly more likely to be accurate than the unselected judgments. This suggests that an implicit link between uncertainty and decision-making might precede the metacognitive ability to explicitly monitor and report uncertainty (Hembacher & Ghetti, 2014).

The aim of the present study is to test this proposal about the development of implicit and explicit awareness of uncertainty by extending this investigation to children's exploratory behavior. Specifically, if decision-making provides early implicit access to knowledge states, then children's sensitivity to uncertainty should be apparent in their exploratory actions *before* they are able to produce explicit confidence judgments. Prior work shows that children (Kloo et al., 2017), infants (e.g., Kidd et al., 2012), and even non-human primates (e.g., Beran et al., 2013; Call & Carpenter, 2001; Marsh & Macdonald, 2012; Paukner et al., 2006) modify their information-seeking behavior in light of uncertainty. However, prior studies have not compared differences in exploratory behavior to explicit confidence judgments about the same stimuli. Further, differences in task design prevent meaningful comparisons to the existing literature on uncertainty monitoring and control.

The current project addresses this gap by assessing preschooler's confidence judgments and spontaneous exploration decisions for the

RESEARCH HIGHLIGHTS

- We assess children's confidence judgments and exploration decisions for the same set of differently occluded stimuli.
- Children spontaneously choose to explore where they have uncertainty, but do not indicate this uncertainty in their explicit confidence judgments.
- Following observation of disconfirming evidence, children's confidence judgments improve, even in the absence of training or feedback.
- Children intuitively recognize uncertainty in their exploratory behavior and surprising or unexpected events can leverage this sensitivity to improve their explicit confidence judgments.

same set of items, which differ in the amount of information they provide. Specifically, children were presented with a set of 'windows' with shapes hidden inside. The windows varied in their degree of occlusion of the shapes, ranging from completely visible to completely obscured. Children were asked either to rate their confidence about the identity of the shape inside each window using a confidence scale (Experiment 1) or to choose which of the windows to explore (Experiment 2). If children preferentially explore less certain windows, but cannot accurately report their uncertainty about them, this would provide support for Hembacher and Ghetti's (2014) claims about the development of metacognition and serve to directly link these two areas of research for the first time.

A second aim of the current research is to investigate the role of *disconfirming evidence* in supporting children's early recognition of uncertainty. As noted above, children preferentially explore surprising or inconsistent events, suggesting that these observations might signal that their existing knowledge is incomplete or incorrect (e.g., Bonawitz et al., 2012; Cook et al., 2011; Schulz & Bonawitz, 2007). Although Ghetti et al. (2013) proposed that the ability to introspect on one's own uncertainty might emerge from repeated exposure to uncertain outcomes, to our knowledge, this claim has never been tested directly. We therefore examine whether disconfirming evidence improves children's ability to accurately report their uncertainty.

To do this, we first measured preschoolers' spontaneous confidence judgments prior to receiving any evidence. In an important departure from previous work eliciting these judgments, children were not trained to use the confidence scale, nor were they allowed to calibrate their responses over multiple judgments (e.g., Hembacher & Ghetti, 2014; Lyons & Ghetti, 2013). That is, children were taught the labels for each point on the scale, but never received direct feedback on their use of these points when making judgments. After establishing children's baseline confidence judgments for each window, the shapes inside of each one were revealed. Critically, some of the shapes were altered in a way that was entirely concealed when they were hidden behind partial occlusion (see Figure 1). The identity of these shapes therefore

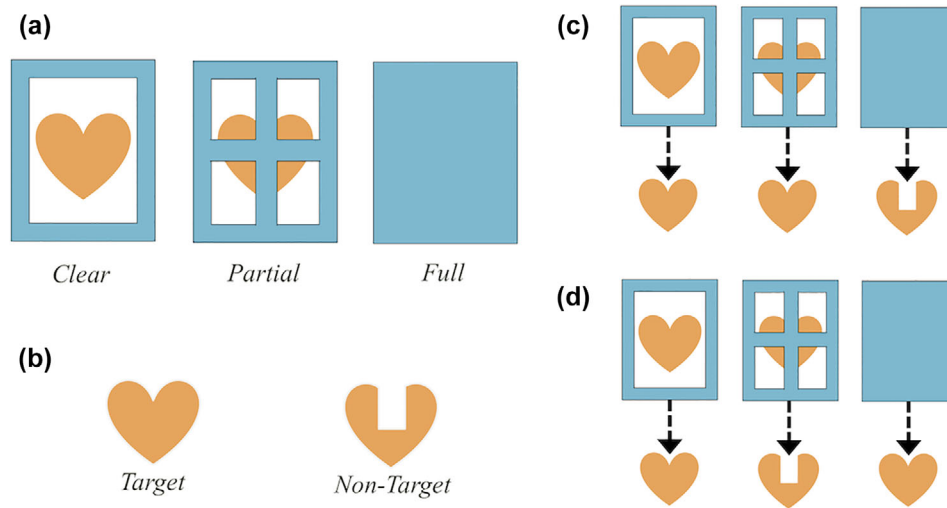


FIGURE 1 Task stimuli. (1a) The three ‘windows’ (Clear, Partial, and Full), with a heart as the target shape. (1b) The ‘target’ and ‘non-target’ heart shapes. (1c) The non-target shape revealed from behind the Full window. (1d) The non-target shape revealed from behind the Partial window (disconfirming evidence)

appeared obvious from the information available, and the reveal violated children’s (reasonable) expectation. We predict that this disconfirming evidence may alert children to the presence of uncertainty and improve the accuracy of their explicit confidence judgments on subsequent trials, even in the absence of direct feedback.

2 | EXPERIMENT 1

Experiment 1 examines children’s explicit confidence judgments before and after observing disconfirming evidence. On each trial, children observed three different ‘windows’ with shapes hidden inside (Figure 1a). The ‘Clear’ window was an empty frame, leaving the shape entirely visible and unambiguous. The ‘Partial’ window’s frame included a cross bar, concealing a portion of the shape. The ‘Full’ window was entirely obscured. We asked children to report how ‘sure’ they were about the shape behind each window using a 3-point scale. Following Hembacher and Ghetti (2014), sensitivity to uncertainty was indicated when children used the different scale values to appropriately distinguish among the levels of ambiguity present (e.g., “very sure” for the Clear window versus “not sure” or “a little bit sure” for the Full and Partial windows). After children provided ratings, the contents of each window was revealed, one of which always contained the surprising cut out shape (Figure 1b). Since the cut out was completely concealed by the crossbar of the Partial window, trials in which this shape was revealed in that location (Figure 1d) served to disconfirm children’s expectation about its identity.

2.1 | Method

2.1.1 | Participants

Forty-three 4- and 5-year-olds ($M = 59.79$ months, $SD = 6.34$, range: 49–71 months) participated in Experiment 1. Sample size was initially

modeled on previous confidence scale research (e.g., Hembacher & Ghetti, 2014; Lyons & Ghetti, 2011). In addition, post-hoc power analyses indicated power of at least 0.8 for all significant results. An additional 13 children were excluded, due to failure to pass the comprehension check (6), caretaker interference (2), or failure to complete the entire task (5). Demographics of the recruitment locations (local preschools and science museums) suggest the participants were predominately white (44.5%) and middle-class (median household income of \$73,900). All studies were approved by the University of California, San Diego, Human Research Protections Program under the project name “Causal Learning and Reasoning in Children” (Study Number: 800997) and written informed consent was obtained from parents of all participants.

2.1.2 | Materials

Two common confidence scales were used: half of participants received a ‘smiley face’ scale (e.g., Hicks et al., 2001) and half received a ‘cartoon scale,’ depicting a child presenting facial expressions and body language corresponding to distinct levels of certainty (e.g., Hembacher & Ghetti, 2014).¹

“Windows” were constructed using two sheets of paper (one white, one blue), inserted into a clear plastic sheet protector. The bottom white sheet was used to create a solid background for each window. The top blue sheet was either left intact (Full window) or cut to resemble an open (Clear window) or bisected frame (Partial window) (Figure 1a).

Paper shapes (circles, hearts, squares, and rectangles) could be placed inside the windows by sliding them between the top and bottom sheets. Two types of shapes were created. ‘Targets,’ included standard instances of each shape, and ‘non-targets,’ included each shape with a part cut out (Figure 1b). The cutouts were placed such that the removed portion would be hidden behind the crossbar of the Partial

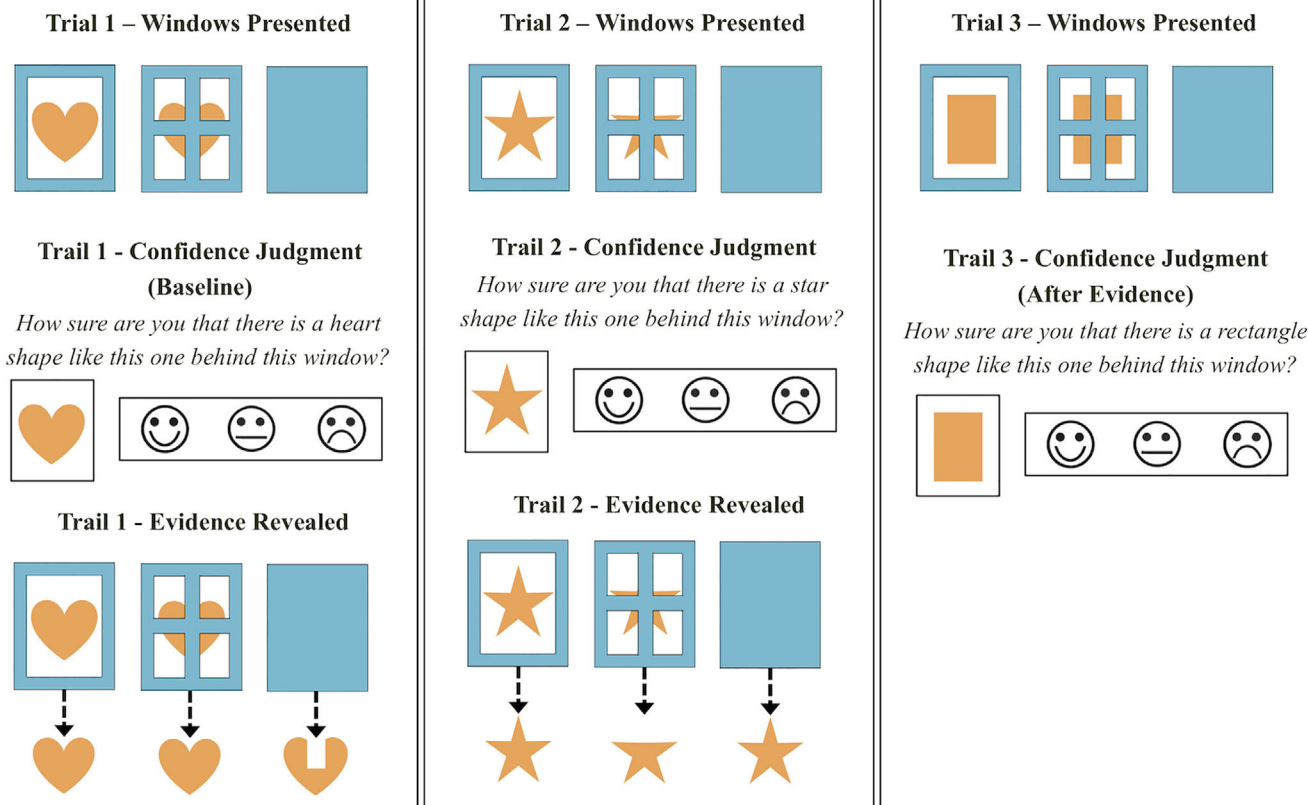


FIGURE 2 The procedure for data collection in Experiment 1. Note that the trial in which disconfirming evidence was revealed was counterbalanced, with half of participants observing this evidence on Trial 2 (as shown here). The shapes presented on each trial (heart, star, rectangle) were randomized

window. This meant that targets and non-targets would look identical at this level of occlusion. Reference cards with images of the target shapes of the same size and color as those placed inside the windows were also used.

2.1.3 | Procedure

At the beginning of the task, the experimenter arranged three empty windows (Full, Partial, and Clear) in a row on the table. The order of the windows was randomized and counterbalanced across trials and participants. The experimenter explained that shapes could be placed inside the windows, and demonstrated by taking three identical paper shapes and placing one inside each window. This allowed children to observe how the same shape looked behind each level of occlusion.

Children were also introduced to the confidence scale. Following previous work, they were instructed to point to the image that represented how sure they were (i.e., “not sure,” “a little bit sure,” or “very sure”). To ensure that any differences in performance reflected differences in understanding rather than the ability to map the labels to each scale point, children were given a comprehension check (“Which one do you point to when you’re [very, a little bit, not] sure?”) for all three levels of confidence. If a child answered incorrectly, they were told “No, silly!”

and asked to try again. Children who were unable to indicate the correct face after two attempts to answer each question were dismissed from the study and excluded from analysis ($n = 6$).

Test Trials. Following this familiarization, three test trials were conducted (see Figure 2). At the start of Trial 1, the experimenter laid out three new windows (Full, Partial, and Clear), with paper shapes already inside them. The experimenter then held up the reference card with an image of the target shape, and said, “some of these windows have a [shape] like this behind them, and some of these windows have a different shape behind them.” The experimenter asked participants to use the confidence scale to indicate their certainty that the target shape was behind each window in turn. For each window, the experimenter repeated the question and named the scale points, saying, “Are you very sure, a little bit sure, or not sure at all?” while pointing to the corresponding image. Children were instructed to respond by pointing to the scale.

After children produced baseline confidence judgments for all three windows, the experimenter revealed the shape concealed behind each. Two target shapes and one non-target shape were revealed on each trial. The Clear window always contained a target shape, and the non-target shape was revealed to be inside *either* the Partial or Full window. “Disconfirming evidence” was defined as revealing a non-target shape from behind the Partial window, which violated children’s

expectation that it contained a target shape (see Figure 2, 'Trial 2 – Evidence Reveal'). To avoid biasing children to believe that Partial windows always contained non-target shapes, disconfirming evidence was presented on only one of the first two trials (on the other trial, the non-target shape was behind the Full window). The order of presentation of disconfirming evidence alternated across participants.

After revealing each shape, the experimenter removed the windows, shapes, and reference card from the table and began the next trial. Trials 2 and 3 were conducted using an identical procedure, but a different target shape. Confidence scale responses were coded as items on an ordinal scale: ('very sure' = 3, 'little bit sure' = 2, and 'not sure at all' = 1).

2.1.4 | Results

To identify the factors influencing children's confidence ratings, a cumulative link mixed model (CLMM) was determined for each combination of factors and tested against a null model. Participant ID was included as a random effect, since tendency towards overconfidence may differ by individual. For CLMM fitting, we used the R package, Ordinal (see Christensen, 2015). The full model, which included age, window type (Full, Partial, Clear), trial type (Trial 1, Trial 3), interaction between window and trial, and interaction between window, trial, and age, performed best against the null model, $X^2(5) = 12.32$, $p = 0.031$. To look at the effect of each factor, we then considered a model that included only age, which did not outperform the null, $X^2(1) = 0.03$, $p = 0.867$. Each of the factors subsequently added to the model improved the fit significantly (window, $X^2(2) = 16.56$, $p < 0.001$; interaction between window and trial type, $X^2(2) = 15.62$, $p < 0.001$) or marginally (trial type, $X^2(1) = 3.14$, $p = 0.076$). Pairwise comparisons further exploring the influence of window, trial, and their interaction are reported below.²

2.1.5 | Baseline confidence judgments

On Trial 1, children showed no differences in confidence ratings across any of the windows (see Table 1 for frequency data). Mann-Whitney tests revealed that confidence ratings for the Clear window (median = 3) did not differ from those of the Full (median = 3), ($W = 911$, $p = 0.896$) or Partial (median = 3), ($W = 888.5$, $p = 0.721$) windows. Median confidence rating for the Full and Partial windows also did not differ, (Mann-Whitney, $W = 950$, $p = 0.804$).

2.1.6 | Confidence judgments following disconfirming evidence

To examine the effect of disconfirming evidence on children's confidence judgments, we compared responses on Trials 1 and 3 (see Table 1). As predicted, confidence ratings for the Full window (median = 2) were significantly lower after observing disconfirming

TABLE 1 Frequency of responses on Trial 1 (Baseline, prior to evidence) and Trial 3 (After observing disconfirming evidence) of Experiment 1

	Full Window	Partial Window	Clear Window
Trial 1			
Not Sure At All (1)	4	7	7
Little Bit Sure (2)	13	10	8
Very Sure (3)	26	26	28
Trial 3			
Not Sure At All (1)	16	11	3
Little Bit Sure (2)	13	13	3
Very Sure (3)	14	19	37

evidence (Mann-Whitney, $W = 1260.5$, $p = 0.001$). Confidence ratings for the Partial window were also lower on Trial 3 (median = 2) but this change did not reach significance (Mann-Whitney, $W = 1084.5$, $p = 0.13$). There was also a significant increase in confidence for the Clear window (median = 3, Mann-Whitney, $W = 732.5$, $p = 0.028$).

Analysis of Trial 3 confidence ratings indicates that these changes were due to an overall improvement in children's performance. Following their experience of disconfirming evidence, children's judgments differentiated between different levels of uncertainty, with significantly *higher* confidence ratings for the Clear window (median = 3) than for either the Full (median = 2; Mann-Whitney, $W = 425.5$, $p < 0.001$), or Partial (median = 2; Mann-Whitney, $W = 540.5$, $p < 0.001$) windows. The ratings for Full and Partial windows were not significantly different, Mann-Whitney, $W = 784.5$, $p = 0.2$.

2.1.7 | Discussion

Here we examined preschoolers' explicit uncertainty monitoring by recording their confidence scale ratings before and after observing disconfirming evidence. On Trial 1, we examined children's *spontaneous* use of a 3-point confidence scale. Median confidence ratings did not indicate sensitivity to different levels of uncertainty: children gave roughly the same confidence rating for all three windows. These results seem to suggest, that in the absence of training to use a confidence scale, children fail to accurately report their uncertainty.

In light of past work suggesting that 4- and 5-year-olds may be on the cusp of a developmental shift in their uncertainty awareness (Rohwer et al., 2012), we predicted that observing disconfirming evidence would facilitate children's explicit recognition of uncertainty. Our findings are consistent with this prediction: Trial 3 confidence ratings distinguished complete information (Clear window) from both complete (Full window) and partial (Partial window) uncertainty. Not only were confidence ratings for the Full window significantly lower between Trials 1 and 3, ratings for the Clear window were also significantly *higher* – indicating increased accuracy of children's explicit judgments rather than a general decrease in confidence. Given that



children only received three trials, and were not provided with feedback from the experimenter, this improvement is unlikely to be due to mere exposure to the confidence scale. Instead, these findings suggest that the experience of surprising, or belief-violating outcomes supports children's awareness of uncertainty by highlighting their incomplete knowledge.

However, a possible alternative is that the difference between Trials 1 and 3 is due to a change in children's subjective feelings of uncertainty, rather than an improvement in their explicit confidence judgments. That is, children may have been genuinely confident that the occluded windows contained the target shape on Trial 1 and accurately reported this certainty. If so, we would expect a similar pattern of responding in an implicit measure of uncertainty about the same stimuli. Experiment 2 will allow us to test this alternative.

3 | EXPERIMENT 2

Experiment 2 examines children's exploration decisions for implicit recognition of uncertainty. Instead of asking children to explicitly report their confidence about each window, we offered a forced choice to reveal the contents of *one* of the three windows to learn more about the shape inside. This allowed us to examine whether children's spontaneous information-seeking decisions differ from their explicit confidence judgments for the same set of stimuli.

3.1 | Method

3.1.1 | Participants

Forty-five 4- and 5-year-olds ($M = 59.9$ months, $SD = 6.64$, range: 48–72 months) participated in Experiment 2. Three additional children were excluded due to experimenter error (1) or failing to complete the entire task (2). Recruitment procedures and demographics were identical to Experiment 1.

3.1.2 | Materials

Six windows (two of each type), the shapes, and their accompanying reference cards from Experiment 1 were used.

3.1.3 | Procedure

The introduction and familiarization procedure was similar to Experiment 1, except that the confidence scale was not included.

Next, the experimenter again laid out three windows (Full, Partial, and Clear), with shapes already inside. Target shape and window order were counterbalanced across participants. The experimenter explained that some windows contained the shape displayed on the reference card, and some contained different shapes. However, instead of

asking children to rate their confidence, the experimenter offered children an exploration choice, saying: "We can look at what's behind *just one* of these windows. Which window should we look behind to find out more about the shapes?" If children did not spontaneously select a window to explore, they were prompted to point to their choice.

4 | RESULTS

The vast majority of children (88.98%) spontaneously chose to explore one of the two uncertain windows at baseline. Indeed, children showed a significant preference to explore where they had the greatest uncertainty, with 64.44% choosing the Full window, $X^2(2, N = 45) = 20.8$, $p < 0.001$. Of the remaining children, 24.44% chose to explore the Partial window, and only 11.11% chose to explore the Clear window.

5 | DISCUSSION

Experiment 2 employed a modified version of the first trial of Experiment 1 to examine how preschoolers would choose to explore the same stimuli as an implicit measure of their sensitivity to uncertainty. The results are consistent with past work showing children's preference to explore what is ambiguous or surprising: The majority of children spontaneously chose to explore where they had no information, and almost all chose to explore where there was some uncertainty. This contrasts with the baseline responses from Experiment 1, where explicit confidence judgments did not spontaneously distinguish between the clear and occluded windows, and suggests that 4- and 5-year-olds are already intuitively aware of the presence of uncertainty in the context of their exploration decisions. These results also rule out the alternative interpretation that children's high explicit confidence judgments at baseline accurately reflected their subjective feelings of certainty about the contents of the occluded windows.

6 | GENERAL DISCUSSION

This research examined early sensitivity to uncertainty in both the explicit confidence scale judgments and implicit exploration decisions of preschool-aged children. As in prior work, children's explicit ratings tended towards overconfidence and did not initially distinguish among different degrees of uncertainty. In Experiment 1, we provide novel evidence that observing an unexpected outcome facilitates children's subsequent uncertainty judgements. This finding compliments and extends past work showing that surprising outcomes may be critical for initiating, motivating, and retaining information during learning (see Brod, 2021 for review; also Brod et al., 2018; Stahl & Feigenson, 2015, 2017), and raises the intriguing possibility that these experiences may also play a role in the early development of metacognition. When the experimenter revealed a cutout shape from behind the Partial window, it violated children's reasonable belief that this window contained the target shape. This event may have highlighted the

presence of uncertainty for children, either by associating the experience of being incorrect about an outcome with their implicit uncertainty, or by altering their expectations about possible outcomes. Future work is needed to examine the precise mechanisms underlying the effects of surprise on metacognition and to further explore the potential for applying this strategy to support and improve children's explicit confidence judgments.

In Experiment 2, we show that children's exploration decisions are more sensitive to the presence of uncertainty, even at baseline. Together, these studies represent the first attempt to compare children's information-seeking decisions (as a measure of implicit uncertainty control) to their explicit confidence scale ratings of the same stimuli. While differences in the response type across measures prevent direct statistical comparison, we report striking differences in children's sensitivity to uncertainty in Experiments 1 and 2. In Experiment 1, children initially reported roughly equal (high) confidence for all three windows. In contrast, children's spontaneous responses in Experiment 2 distinguished among the windows, preferentially exploring where they had incomplete information, even without the experience of disconfirming evidence. This result is consistent with recent findings that young children recognize and react to uncertainty in their exploration behavior before they are able to explicitly articulate this understanding (e.g., Cook et al., 2011; Lapidow & Walker, 2020; Siegel et al., 2021). The current studies therefore not only provide novel evidence for an early developing, implicit sensitivity to uncertainty (e.g., Ghetti et al., 2013; Hembacher & Ghetti, 2014), but also suggest that the purpose of this sensitivity may be to motivate and guide the self-directed exploration behavior that is central to early learning.

A possible alternative interpretation is that measures of uncertainty control are simply more intuitive than measures of uncertainty monitoring. That is, asking children what they want to explore, study (Destan et al., 2014), skip (Lyons & Ghetti, 2013), seek help on (Coughlin et al., 2015), or have evaluated (Hembacher & Ghetti, 2014) is easier for young children to understand than asking them to rate items on a scale. Pulling apart the effects of implicit understanding from asking more intuitive questions on children's performance is beyond the scope of the current studies. However, this distinction highlights the value of applying more intuitive empirical measures of explicit uncertainty monitoring in future work.

The current research draws a novel connection between the literatures examining children's confidence judgments and their self-directed exploration. We find that children's explicit confidence judgments improved following disconfirming evidence and that they showed relatively greater sensitivity to uncertainty in their exploration decisions. Taken together, these results suggest that children's early developing uncertainty control may play a role in their decision-making during information search, and that this implicit sensitivity may be used to support and measure children's early recognition of what they don't know.

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CONFLICT OF INTEREST STATEMENT

Elizabeth Lapidow, Isabella Killeen, and Caren Walker declare that they have no conflict of interest.

ETHICS APPROVAL STATEMENT

All procedures performed were in accordance with the 1964 Helsinki declaration and approved by the Institutional Review Board.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in OSF, at <https://doi.org/10.17605/OSF.IO/FXZHM>.

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NOTES

- 1 Type of confidence scale was randomly assigned and no difference in performance was found, so data were combined for all analyses.
- 2 Since the data are ordinal, medians and Mann-Whitney tests are used for pairwise comparisons.

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