Beyond belief: The probability-based notion of surprise in children

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Abstract

Improbable events are surprising. However, it is unknown whether children consider probability when attributing surprise to other people. We conducted four experiments that investigate this issue. In the first three experiments, children saw stories in which two characters received a red gumball from two gumball machines with different distributions, and children then judged which character was more surprised. Experiment 1 ($N = 120$) shows development in children's use of probability to infer surprise. Children aged 7 correctly inferred that the character with a lower chance of getting a red gumball would be more surprised, but 4 – 6-year-olds did not. Experiment 2 ($N = 120$) shows that children's performance does not improve when the probability of getting a red gumball is zero and should be maximally surprising. Experiment 3 ($N = 120$) demonstrates that 6-year-olds' performance improves when they are prompted to consider probabilities, but not when they are prompted to consider the characters' beliefs. Experiment 4 ($N = 60$) replicates this finding, but using a new design in which children attributed emotions to just a single character. Together these findings suggest that by age 6, a conceptual shift occurs, in which children begin to integrate their understanding of probability with their understanding of surprise.

Keywords: emotion attribution, surprise, probability, social cognition, conceptual development

Beyond belief: The probability-based notion of surprise in children

Probability and surprise go hand in hand – improbable events are surprising, but probable ones are not. For example, you might be surprised if you run into a high school friend while vacationing on a remote island, but you probably will not be surprised if you see the same friend at your high school reunion. This connection between probability and surprise is present in adults' conceptions of surprise, as they attribute surprise to agents who observe improbable outcomes (e.g., Maguire, Maguire, & Keane, 2011; Teigen & Keren, 2003).

However, it is unknown whether children consider probability when inferring surprise. Previous research has not examined this, as most research on children's understanding of surprise relates it to their understanding of others' beliefs. When children explain why a character was surprised by an outcome, 4-year-olds refer to the character's beliefs, though 3-year-olds refer to the character's desires (Wellman & Banerjee, 1991; Wellman & Bartsch, 1988). For example, 4-year-olds might say a boy is surprised that his grandmother's house is purple because he thought the house would be white, whereas 3-year-olds might say he is surprised because he likes purple (Wellman & Banerjee, 1991). Further, 4- and 5-year-olds appropriately attribute surprise to characters whose beliefs are not met, but refrain from attributing surprise to characters whose desires are not met (Hadwin & Perner, 1991; Wellman & Bartsch, 1988). Finally, children who correctly infer another's beliefs are also better at predicting their surprise. For example, when 3- to 8-year-olds judge which of two boxes will surprise a puppet, only children aged 5 and up, who correctly infer the puppet's beliefs about the contents of the boxes, choose the correct box. This finding suggests that in order to understand surprise, children must first understand beliefs (MacLaren & Olson, 1993; also see Ruffman & Keenan,

1996 and Scott, 2017 for conflicting evidence about whether inferring surprise from false belief emerges later or earlier in development).

Children may also use probability to infer surprise. This is plausible, as adults infer surprise in this way (e.g., Maguire et al., 2011; Teigen & Keren, 2003). For example, when asked to make probability and surprise judgments about an occurrence of rainfall, adults rated their surprise as greater when the probability of rain was lower (Maguire et al., 2011). It is important to note that such probability-based inferences may not require attributing beliefs. Adult participants could have attributed surprise by only considering the probability of rain occurring, and without attributing any beliefs to themselves regarding whether it would rain. Thus, belief understanding might not be the *only* requisite for inferring surprise.

If children also use probability to infer surprise, this will advance knowledge of how children understand surprise, and how they infer emotions more broadly. Existing accounts suggest that children have two ways of understanding others' emotions (Harris, de Rosnay, & Pons 2016; Widen & Russell, 2010). The first way depends on learning and memorizing scripts (Barden, Zelko, Duncan, & Masters, 1980; Harris, Olthof, Terwogt, & Hardman, 1987; Widen & Russell, 2010, 2011). For example, children may remember *specific* antecedents and consequences of happiness and use this to infer happiness in the future (e.g., people are happy when they receive birthday presents). The second way children are thought to infer emotions is by considering others' mental states (Harris, Johnson, Hutton, Andrews, & Cooke, 1989; Lagattuta, 2005, 2008; Rieffe, Terwogt, & Cowan, 2005; Ronfard & Harris, 2014; Skerry & Spelke, 2014; Wellman & Bartsch, 1988; Wellman & Woolley, 1990). For example, young children understand that a boy will be happy if his desires are fulfilled, but will be sad if his desires are unfulfilled (Wellman & Woolley, 1990). Using probability to infer surprise does not

fit under either theory. Scripts are composed of specific concrete events (e.g., Abelson, 1981), and do not make reference to underlying abstract concepts, like probability (for further discussion see Gopnik & Meltzoff, 1997, p. 62). Likewise, notions of probability are not included in children's notions of others' mental states. Hence, if children also use probability to infer surprise, this will reveal another method of understanding emotions, as it will show that their understanding of surprise depends on their probabilistic reasoning.

Investigating whether children use probability when attributing surprise will also advance our understanding of probabilistic reasoning in children. Children consider probability information from early in development. In violation of expectation paradigms, infants as young as 6 months expect probable outcomes, and look significantly longer at improbable ones (Denison, Reed, & Xu, 2013; Teglas et al., 2007; Xu & Garcia, 2008). Preschool-aged children also use probability in social inferences, such as when inferring another person's preferences based on the objects they sample from various distributions (Kushnir, Xu, & Wellman, 2010; Ma & Xu, 2011). If the individual takes a few duck toys from a box containing duck and frog toys, children infer that the individual prefers duck toys only if the box contains mostly frog toys, and not if the box contains mostly duck toys (Kushnir et al., 2010). In these cases, a preference for ducks is inferred because removing only ducks from a mostly frog population violates random sampling and signals an intentional act. Together these findings suggest that infants use probability to guide their own expectations and that slightly older children use probability in social inferences. If children also use probability to infer emotions, this will expand our knowledge of its influence in children's social cognition. Further, investigating how this ability develops could be informative about how children relate and integrate concepts from different domains.

In four experiments, we investigate children's ability to use probability to explicitly attribute surprise to another person. In the first three experiments, children saw stories in which two characters received a red gumball from different gumball machines. One machine contained mostly red gumballs and the other machine contained only a minority of red gumballs. Children were asked which character was more surprised with the outcome. In the fourth experiment, we used a slightly different method, in which children attributed emotions to a single character. These four experiments investigate the development of children's use of probability in inferring surprise and two manipulations intended to make the connection between probability and surprise more apparent to younger children.

Experiment 1

Experiment 1 investigated the development of children's ability to use probability to infer surprise. Children were told stories about two characters at two different gumball machines and were asked to choose the character who was more surprised after seeing both characters receive a red gumball. To succeed, children had to appreciate that although getting a red gumball was probable for one character, it was improbable for the other character, making the outcome surprising.

Method

Participants. One hundred and twenty children participated: 30 4-year-olds ($M = 4;7$ [years; months]; range = 4;3 – 4;11; 15 girls), 30 5-year-olds ($M = 5;5$; range = 5;0 – 5;11; 14 girls), 30 6-year-olds ($M = 6;6$; range = 6;0 – 6;11; 13 girls), and 30 7-year-olds ($M = 7;4$; range = 7;0 – 7;11; 13 girls). In all experiments, children were individually tested at schools and daycares in the Waterloo Region. Demographic information was not formally collected, but the region is predominantly middle-class, and approximately 79% of residents in this region are

Caucasian, with Chinese and South Asians as the most visible minority. Different children were tested in each experiment. This research, submitted under the name, “Social Understanding in Children” (ORE#20042), received ethics clearance through the University of Waterloo’s Research Ethics Committee.

Materials and procedure. All materials in the current experiment and the following experiments were shown on a laptop computer. Children were told two stories (2 trials). Each story was about two gumball machines. One machine contained many red gumballs and just a few black ones (36 red, 4 black), and the other machine contained the reverse distribution (36 black, 4 red). We used this distribution (9:1) to ensure that children would readily notice that one color was more plentiful than the other (e.g., Denison, Bonawitz, Gopnik, & Griffiths, 2013; Girotto, Fontanari, Gonzalez, Vallortigara, & Blaye, 2016). Children were told that the red gumballs are yummy and the black gumballs are yucky. Two identical-looking characters, always viewed from behind, then appeared, with each character at one machine. The characters were depicted this way to prevent children’s responses from being swayed by extraneous factors, such as differences between the characters, or the expressions on their faces. Children were told that both characters wanted a red gumball, and were asked a comprehension check question to confirm that they understood (i.e., “What color gumball do the girls want?”). The characters pulled the handles of their machines, and each ended up getting a red gumball. Children were then asked which character was more surprised. See Figure 1 for a sample story and script.

In the first story, the characters were girls, the gumball machines were colored green, and they appeared side-by-side. In the second story, the characters were boys, the machines were colored orange, and one appeared above the other. We varied these details to prevent children from repeating or alternating responses across the stories. The location of the gumball machines

was counterbalanced across participants, such that for half the children the mostly-red machine was on the right in the first story and on the top in the second story, and in the opposite locations for the other children.

If children responded incorrectly to the comprehension check question about which type of gumball the characters wanted, the experimenter repeated the information about the tastes of the red and black gumballs. When the comprehension check question was asked again, all children answered correctly.

Figure 1. Sample slides and script from Experiment 1 (Trial 1).

Results and Discussion

Six children initially responded incorrectly to the comprehension check question about which type of gumball the characters wanted (four 4-year-olds; one 5-year-old; one 7-year-old). When these children's data were excluded, our main pattern of results remain the same. Thus, we report our analyses with our full sample.

Of primary interest was whether children are able to use probability to infer the characters' surprise, and whether this ability develops with age; Figure 2 shows children's mean number of correct responses (i.e., choosing the character who was at the machine with fewer red

gumballs). A Generalized Estimating Equations (GEE) binary logistic regression with age as a between-subject factor (4, 5, 6, 7) revealed a significant main effect of age, $Wald\ X^2(df = 3, N = 120) = 13.02, p = .005$. Pairwise comparisons revealed that 4-year-olds gave significantly fewer correct responses compared to children at all other ages, $ps \leq .019$. However, responses did not significantly differ between 5-, 6-, and 7-year-olds, $ps \geq .214$.

We then used Wilcoxon sign tests to examine whether children at each age chose the correct character more or less than half the time (i.e., whether the scores departed from chance score of 1). For these analyses, we summed children's correct responses across both trials for a maximum score of two. Seven-year-olds predominantly chose the correct character ($M = 1.43, SD = .817, z = -2.60, p = .009$), 6-year-olds showed a trend in this direction ($M = 1.27, SD = .785, z = -1.79, p = .074$), 5-year-olds responded at chance ($M = 1.17, SD = .874, z = -1.04, p = .297$), and 4-year-olds predominantly chose the wrong character ($M = 0.67, SD = .802, z = -2.13, p = .033$).

Figure 2. Mean scores for children's surprise judgments in Experiment 1. Error bars show ± 1 standard error of the mean. Dotted line at a score of 1 represents chance performance.

These findings suggest development in children's ability to use probability to infer another's surprise. Although 7-year-olds correctly judged that the character with a lower chance of getting a red gumball was more surprised (and 6-year-olds trended in this direction), 5-year-olds did not make systematic judgments, and 4-year-olds incorrectly judged that the character with a higher chance of getting a red gumball would be more surprised.

One possible interpretation of these results is that 4- and 5-year-olds are insensitive to the probabilities of the distributions in this experiment. However, this is unlikely, as 4-year-olds attributed greater surprise to the character with the more probable distribution, suggesting that even these youngest children were sensitive to the differences between the distributions. Furthermore, it is unlikely that 4-year-olds mistakenly think that the more probable distribution is less likely to yield a red gumball, as previous research suggests that children this age expect the majority item in a distribution to be sampled most often (e.g., Denison et al., 2013; Denison, Konopczynski, Garcia, & Xu, 2006; Girotto et al., 2016).

Another possible explanation for children's poor performance is that they may not yet understand the word "surprise", or may mistakenly think that it means a positive emotion. Some evidence suggests that young children associate surprise with desirable events (e.g., Bartsch & Estes, 1997), attribute positive emotions to the word surprise (Russell, 1990), and know that achieving a goal results in positive emotions (e.g., Skerry & Spelke, 2014; Wellman & Woolley, 1990). However, we tested children aged 4 and older, and previous research shows that children at these ages do understand "surprise", and do not just connect it with positive outcomes (e.g., Hadwin & Perner, 1991; MacLaren & Olson, 1993; Wellman & Banerjee, 1991). For example, 4-year-olds explain surprise by referring to agents' beliefs; a tendency to interpret "surprise" as referring to positive outcomes would instead predict that children should only provide desire-

based explanations (Wellman & Banerjee, 1991). Hence, children misunderstanding the meaning of “surprise” is unlikely to explain our findings.

Although children are not limited to interpreting “surprise” as *referring* to positive events, they may nonetheless *associate* it with such events, and with situations that are likely to have positive results. Because of this, telling children about the desirability of the gumballs (i.e., red ones are yummy; black ones are yucky) may have negatively impacted their performance. It may have biased them to choose the character who had access to the machine with the larger proportion of “yummy” gumballs, as this character was more likely to have positive results (i.e., getting even more good gumballs). This could explain why 4-year-olds showed below chance performance. Thus, in the remaining experiments, the desirability information was removed.

Experiment 2

We examined whether making the gumball distributions more extreme would improve children’s surprise judgments. The experiment included two conditions: improbable and impossible. The improbable condition used the same distribution of gumballs as Experiment 1, to see if the findings would replicate. In the impossible condition, one gumball machine contained only red gumballs and the other machine contained only black gumballs, and so it should have been impossible for one character to get a red gumball. We hoped this distribution would make the improbability of one character getting a red gumball more salient, and maximally surprising. Because 7-year-olds in the first experiment were able to correctly infer surprise using probabilistic distributions, only 4- to 6-year-olds were tested.

Method

Participants. One hundred and twenty children participated: 40 4-year-olds (M age = 4;6 years, range = 4;0 – 4;11; 18 girls), 40 5-year-olds (M = 5;5; range = 5;0 – 5;11; 22 girls), and 40

6-year-olds ($M = 6;3$; range = 6;0 – 6;10; 17 girls). Children were recruited and tested at daycare centres and schools.

Materials and procedure. Children were told two stories (2 trials) about gumball machines and were randomly assigned to one of two conditions. In the improbable condition, one machine contained many red gumballs and just a few black ones (36 red, 4 black), and the other machine contained the reverse distribution (36 black, 4 red). In the impossible condition, one gumball machine contained all red gumballs and the other machine had all black gumballs. In both conditions, two identical-looking characters appeared, with each character at one machine. Children were told that both characters wanted a gumball. The characters pulled the handles of their machines, and each ended up getting a red gumball. Children were then asked which character was more surprised. The script was identical across both conditions, and was as follows:

Here are two gumball machines. They have red gumballs and they have black gumballs. And look, here are two girls. They both want a gumball. To get a gumball, the girls pull down the handles, and the machines shake up all the gumballs. Look! They both got a red gumball. So now I have a question for you. *Which girl is more surprised that she got a red gumball?*

Results and Discussion

Of interest was whether children would be sensitive to the varying distribution of the gumball machines, and whether their surprise judgments would be more accurate for the impossible outcomes. Figure 3 shows children's mean number of correct responses (i.e., choosing the character who was at the machine with fewer (or no) red gumballs). A GEE binary logistic regression with age (4, 5, 6) and condition (impossible, improbable) as between-subject

factors revealed a significant main effect of age, $Wald X^2(df = 2, N = 120) = 7.26, p = .027$.

There was no effect of condition, $Wald X^2(df = 1, N = 120) = 2.24, p = .134$, and no condition by age interaction, $Wald X^2(df = 2, N = 120) = 1.69, p = .431$, though it is possible that a significant interaction would be revealed if we tested a larger sample of children. Pairwise comparisons revealed that 6-year-olds performed significantly better than 4-year-olds, $p = .006$, and 5-year-olds, $p = .038$, but 4-year-olds and 5-year-olds did not differ in their performance, $p > .5$.

We then summed children's correct responses across both trials for a maximum score of two. Wilcoxon sign tests collapsed across conditions revealed that 6-year-olds ($M = 1.33, SD = .764$) predominantly chose the correct character, $z = -2.50, p = .012$, whereas, 4-year-olds ($M = 0.90, SD = .632$), $z = -1.00, p = .317$, and 5-year-olds ($M = 0.98, SD = .768$), performed at chance, $z = -0.21, p > .5$.

Figure 3. Mean scores for children's surprise judgments in Experiment 2 for the impossible and improbable conditions. Error bars show ± 1 standard error of the mean. Dotted line at a score of 1 represents chance performance.

These results reveal age-related improvements in children's ability to use probability to infer surprise. However, children's judgments of surprise did not improve when the outcome was

impossible. Additionally, removing the desirability of the red gumballs moved 4-year-olds' responses closer to chance, suggesting that 4-year-olds' tendency to choose the more probable distribution in Experiment 1 was due to their inability to inhibit the impulse to choose the machine with more "yummy" gumballs. We next examined whether other manipulations might further improve children's ability to infer surprise.

Experiment 3

Thus far, it appears that young children have difficulty using probability to judge surprise. One explanation for this is that younger children do not see a connection between probability and surprise. Alternatively, they might understand that a connection exists, but might not *spontaneously* consider probability when inferring surprise – they might not spontaneously consider that one girl had a better chance of getting a red gumball than the other. A related explanation for young children's difficulty, though, is that they might not spontaneously consider the characters' beliefs about getting a red gumball – they might not spontaneously consider that one girl believed she would get a red gumball and the other did not. On these views, children might perform better if they were explicitly prompted to consider the characters' chances or beliefs before making a surprise inference.

To examine these possibilities, children were asked a prompt question before seeing both characters receive a red gumball. In a belief condition, they were asked which character *thinks* they are going to get a red gumball; in a probability condition, they were asked which character has a *better chance* of getting a red gumball; finally, in a control condition, they were asked which character was at a machine with a particular colored handle (always corresponding to the mostly red machine, as in the belief and probability conditions).

Method

Participants. One hundred and twenty children participated: 60 5-year-olds ($M = 5;6$; range = 5;0 – 5;11; 27 girls), and 60 6-year-olds ($M = 6;4$; range = 6;0 – 6;11; 31 girls). Children were either tested at schools or in a quiet lab setting.

Materials and procedure. Children were again told two stories (2 trials) about two gumball machines. One machine contained many red gumballs and just a few purple ones (36 red, 4 purple), and the other machine contained the reverse distribution (36 purple, 4 red). Two identical-looking characters then appeared, with each character at one machine. Children were told that both characters wanted a gumball. Children were randomly assigned to one of three prompt conditions. We describe these questions by referring to the scripts with the two girls. The belief prompt asked, “Which girl *thinks* she’s going to get a red gumball?”, the probability prompt asked, “Which girl has a *better chance* of getting a red gumball?”, and the control prompt asked, “Which girl is standing beside the machine with a green handle?” After the prompt question, the characters pulled the handles of their machine, and both characters received a red gumball. Children were asked which character was more surprised. See Figure 4 for a sample of the story and script for the probability prompt.

A few children initially failed the prompt question (see Results). When this happened, the experimenter said, “Let’s hear the story again”, repeated the story from the beginning, and re-asked the prompt question. The experimenter repeated the prompt a maximum of two times (only four children needed to have the story repeated twice). All children answered the prompt question correctly after the repetitions.

Figure 4. Sample slides and script of the probability prompt from Experiment 3 (Trial 1).

Results and Discussion

We first examined children's *initial* responses to the prompt questions. Wilcoxon sign tests revealed that children chose the correct character more than would be expected by chance in the belief condition (86% correct), $z = -5.21, p < .001$, and in the probability condition (85% correct), $z = -5.11, p < .001$. In the belief condition, seven 5-year-olds and three 6-year-olds initially failed the prompt question. In the probability condition, seven 5-year-olds and four 6-year-olds initially failed the prompt question. Only one 5-year-old in each condition initially failed the prompt question on both trials. All children answered the control prompt question correctly. These findings demonstrate that children's difficulty when inferring surprise is not a result of an inability to reason about beliefs or probability.

Of primary interest was whether children who were asked the belief and probability prompt questions would perform better than children who were asked the control prompt question. Figure 5 shows children's mean number of correct responses. A GEE binary logistic regression with age (5, 6) and condition (belief, probability, control) as between-subject factors revealed a marginally significant effect of condition, $Wald X^2(df = 2, N = 120) = 5.78, p = .056$, a

marginally significant effect of age, $Wald X^2(df = 1, N = 120) = 3.01, p = .083$ (6-year-olds chose the correct character more often than 5-year-olds), and a marginally significant condition by age interaction, $Wald X^2(df = 2, N = 120) = 5.78, p = .056$. Pairwise comparisons revealed that children in the probability prompt condition performed significantly better than children in the control prompt condition, $p = .012$, but no differences were found between children's performance in the belief and control prompt conditions, $p > .5$. Children's performance in the probability prompt condition was also significantly better than their performance in the belief prompt condition, $p = .040$. Next, we explored the marginally significant condition by age interaction.

We explored each age group separately and found that 6-year-olds' performance differed significantly by condition, $Wald X^2(df = 2, N = 120) = 7.98, p = .019$, but 5-year-olds' performance did not, $Wald X^2(df = 2, N = 120) = 0.84, p > .5$. Pairwise comparisons revealed that 6-year-olds performed significantly better when asked the probability prompt ($M = 1.80, SD = .523$; these means reflect scores summed across the two trials) than when asked the belief prompt ($M = 1.05, SD = 1.00$), $p = .002$, or the control prompt ($M = 1.20, SD = .768$), $p = .003$, but no differences were found between the belief prompt and the control prompt, $p > .5$. Further pairwise comparisons revealed that 6-year-olds performed significantly better than 5-year-olds when prompted about probability, $p = .003$, but performed similarly to 5-year-olds when prompted about belief, $p > .5$, or the control prompt, $p = .426$. We then summed children's correct responses across both trials for a maximum score of two. Wilcoxon sign tests revealed that only 6-year-olds in the probability prompt condition performed above chance levels, $z = -3.77, p < .001$.

Figure 5. Mean scores for children's surprise judgments in Experiment 3 when asked the belief, probability, and control prompt questions. Error bars show ± 1 standard error of the mean. Dotted line at a score of 1 represents chance performance.

These results reveal that prompting 6-year-olds (but not 5-year-olds) to consider probability when inferring surprise improved their judgments, but prompting children of both ages about beliefs did not. Therefore, Experiment 3 provides two novel insights into children's reasoning about surprise: First, asking children to consider probability appears to be more powerful than asking them to consider beliefs when inferring surprise (at least in this task). Second, children may not spontaneously relate probabilities to surprise when they first appreciate its relevance (around age 6), but they do see the importance of probability when prompted to consider it.

Experiments 1 to 3 used a forced-choice paradigm in which children had to determine which of two characters is more surprised. A concern with this methodology is that children may not have thought that *either* character was surprised, and only chose a character because they were required to do so. Another concern with Experiment 3, is that the control condition might have hindered children's performance because the prompt question was irrelevant to the task. We

conducted a final study to address these concerns, while also attempting to replicate the findings from Experiment 3.

Experiment 4

Experiment 4 further examines the effects of prompting children to consider a character's chances and beliefs of receiving a gumball using a more conservative design. In this experiment, children were shown a single character in front of a gumball machine, and were asked either a belief, probability, or control prompt question. The character then received a minority colored gumball, and children were asked two questions. The first asked how the character felt about receiving a gumball. We asked this question to allow children to express that the character was happy – in piloting, we found that children were strongly inclined to say this, regardless of what question about emotions was asked. This is unsurprising given that the character received a nice treat. The second question then asked how the character felt after seeing that the gumball was of the minority color. Of key interest here was whether attributions of surprise would differ depending on the prompt question children were asked. Only 6-year-olds were tested as they were the only age group that showed differences between the prompt conditions in Experiment 3.

Method

Participants. Sixty 6-year-old children participated ($M = 6;6$; range = 6;0 – 6;11; 29 girls). Children were recruited and tested at schools or in a museum.

Materials and procedure. Children were first familiarized to four faces – a neutral face, a happy face, a sad face, and a surprised face. Children were asked to identify each of the faces in a forced-choice pointing task (e.g., “Which face shows feeling happy?”); two different orders were randomly generated and used when asking children to identify the faces and children were randomly assigned to an order. After children identified each face, the experimenter repeated

which emotion each face depicted, in the order that the faces were asked about. See Figure 6 for an example of the faces and questions asked.

Figure 6. Example script and faces used to familiarize children to the four emotions in Experiment 4.

Next, children were told two stories (2 trials, order counterbalanced across participants). In one story, a girl was at a gumball machine with many green gumballs and only a few orange ones; in the other story, a boy was at a gumball machine with many purple gumballs and only a few red ones. For ease of exposition, we describe the procedure from the story with the girl. Children saw a girl appear at a gumball machine, and were told that she wanted a gumball. Children were randomly assigned to one of three prompt conditions. The belief prompt asked, “Which color gumball does the girl *think* she’s going to get?”, the probability prompt asked, “Which color gumball does the girl have a *better chance* of getting?”, and the control prompt asked, “Which color gumball does the girl *see more of*?” After the prompt question, the girl pulled the handle of the machine, and received an orange gumball. The faces showing four emotions then appeared, and children were asked, “How does the girl feel about getting a gumball?”, and “How does the girl feel when she sees that the gumball is orange?”, respectively.

Children responded by pointing to one of the faces. See Figure 7 for a sample of the story and script for the probability prompt.

A few children initially failed the prompt question (see Results). When this happened, the experimenter said, “Let’s hear the story again”, repeated the story from the beginning, and re-asked the prompt question. All children answered the prompt question correctly after the repetition.

Figure 7. Sample slides and script of the probability prompt from Experiment 4.

Results and Discussion

We first examined children’s *initial* responses to the prompt questions. Wilcoxon sign tests revealed that children chose the correct colored gumballs more than would be expected by chance in the belief condition (70% correct), $z = -2.53$, $p = .011$, and in the probability condition (85% correct), $z = -3.50$, $p < .001$. In the belief condition, eleven 6-year-olds initially failed the prompt question. In the probability condition, five 6-year-olds initially failed the prompt question. Only one 6-year-old in each condition initially failed the prompt question on both trials. All children answered the control prompt question correctly.

As predicted, when asked how the character felt about receiving a gumball, the majority of children (75%) answered “happy”. Of primary interest was whether children who were asked the belief and probability prompt questions would attribute surprise to the character more than children who were asked the control prompt question when asked how the character felt about receiving a minority colored gumball. Figure 8 shows the mean number of times children indicated that the character would be surprised. A GEE binary logistic regression with condition (belief, probability, control) as a between-subject factor revealed a significant effect of condition, $Wald X^2(df = 2, N = 60) = 8.97, p = .011$. Pairwise comparisons revealed that children in the probability prompt condition ($M = 1.20, SD = .951$), attributed surprise to the character significantly more than children in the control prompt condition ($M = 0.35, SD = .671$), $p = .001$, but no differences were found between children’s performance in the belief ($M = 0.65, SD = .875$) and control prompt conditions, $p = .212$. Children in the probability prompt condition also attributed surprise to the character marginally more than children in the belief prompt condition, $p = .051$. We then summed children’s attributions of surprise across both trials. Wilcoxon sign tests revealed that only children in the probability prompt condition chose surprise at above chance levels, with chance being 0.50 out of 2, as there were four possible emotions to choose from and two trials, $z = -2.69, p = .007$.

Figure 8. Mean number of times children attributed surprise in Experiment 4 when asked the belief, probability, and control prompt questions. Error bars show ± 1 standard error of the mean. Dotted line at a score of 0.5 represents chance performance.

These results replicate Experiment 3 using a different methodology. We found that prompting 6-year-olds to consider probability led to an increase in their surprise attributions, but prompting them to consider belief did not have this effect. By allowing children to choose between four different emotions, we were able to see the cases in which children would choose surprise over other emotions. We also ruled out the concern that the control prompt in Experiment 3 might have confused children, as they continued to perform poorly in the control prompt condition in this experiment. Together, Experiments 3 and 4 show that for 6-year-olds, the link between probability and surprise is stronger than the link between belief and surprise.

Although all of our Results sections included analyses from both trials, we also ran analyses that only included data from the first trial. The results of these analyses were qualitatively similar with our main analyses, though some significant results became marginal due to the loss of statistical power. Because these analyses do not change the interpretation of our findings, we did not include them.

General Discussion

In four experiments, we examined children's ability to use probability when explicitly inferring other people's surprise. Children's performance improved with age. Whereas 4- and 5-year-olds did not use probability to infer surprise, 6-year-olds did so inconsistently, and only 7-year-olds did so reliably (Experiments 1 and 2). When getting a red gumball was impossible, and maximally surprising, children's performance did not improve (Experiment 2). When children were prompted to consider either the characters' chances or beliefs of getting a red gumball, only the prompt about probability improved 6-year-olds' performance (Experiments 3 and 4). Together these findings suggest that children aged 5 and under fail to use probability to infer surprise, and that children aged 6 only have a limited ability to make these inferences (i.e., they require prompting to consistently infer surprise from probability). It is only by age 7 that children have a robust ability to infer surprise from probability.

The present experiments provide the first evidence that children use probability to infer others' emotions. Theories of children's emotional understanding posit two ways in which children understand the causes of emotions – relying on memorized scripts (e.g., Harris et al., 1987; Widen & Russell, 2010, 2011), and considering mental states (e.g., Skerry & Spelke, 2014; Wellman & Woolley, 1990). Neither theory refers to probability or related concepts. Our experiments suggest that these theories are insufficient for characterizing the factors that influence children's emotion attributions, at least in the case of reasoning about surprise. Future work is required to determine whether probabilistic inference influences children's other emotion attributions.

Furthermore, our findings advance knowledge of children's understanding of surprise. They call into question the notion that children mainly conceptualize surprise in terms of beliefs,

which is prevalent in the developmental literature, given that most research on surprise in childhood focuses on beliefs (e.g., Hadwin & Perner, 1991; MacLaren & Olson, 1993; Ruffman & Keenan, 1996; Wellman & Banerjee, 1991). We found that 6-year-olds' performance improved when they were prompted to consider probability, but not when they were prompted to consider the character's belief. If surprise were purely belief-based in childhood, then prompting children to consider beliefs should have improved their performance. At a minimum, these findings suggest that children's understanding of surprise is not just belief-based, but also probability-based.

Development and a Conceptual Shift

The development of children's ability to use probability to explicitly infer surprise is strikingly slow given that probability influences children's expectations early in development. Very young children correctly reason about probability (e.g., Denison et al., 2006, 2013; Girotto et al., 2016) and use it to make sophisticated social inferences (Kushnir et al., 2010; Ma & Xu, 2011). In our studies, we also found that children correctly responded to the prompt question about probability (Experiments 3 and 4), demonstrating that they are capable of probabilistic reasoning. Yet our findings suggest that children cannot use their understanding of probability to infer surprise until at least 6 years of age.

If even infants and preschoolers use probability in social inferences, why do young children struggle to use probability when inferring surprise? One possibility is that their difficulty stems from immature inhibitory control. Inhibitory control, the ability to suppress impulsive responses to stimuli, develops over children's preschool years, improving immensely between the ages of 3 and 6 (e.g., Carlson & Moses, 2001; Carlson & Wang, 2007). In our experiments, both machines produce a red gumball; however, one machine always has more red

gumballs than the other. Young children may have difficulty inhibiting the impulse to match the outcome (red gumball) to the mostly red gumball machine. However, this account is unlikely to explain all of the difficulties observed by children in our experiments. Older 4-year-olds are proficient at conflict inhibition tasks, which require them to provide a response that is incompatible with their impulsive response (Carlson, 2005; Carlson & Moses, 2001). Thus, 5-year-olds should have easily overcome the inhibitory demands of our task.

It is more plausible that children's difficulty stems from a conceptual deficit. On this view, children aged 5 and under have independent understandings of probability and surprise, but do not see how they relate. By age 6, a conceptual change occurs, in which children come to integrate and relate their understandings of probability and surprise, although it is not until age 7 that they *spontaneously* link the two concepts. Consistent with this account, previous studies show that children correctly reason about probability in explicit tasks by age 4 (e.g., Denison et al., 2006, 2013; Girotto et al., 2016), and they successfully infer surprise at ages 4 – 5 (e.g., Hadwin & Perner, 1991; MacLaren & Olson, 1993; Wellman & Banerjee, 1991; Wellman & Bartsch, 1988). Also, in our third experiment, when 5-year-olds were explicitly prompted to consider probability, they were still unable to use this information to infer surprise, suggesting that they had difficulty integrating probability with surprise. Future research can explore why the connection between probability and surprise arises relatively late in development, and what experiences are needed for this conceptual shift to occur.

Open Questions and Future Directions

Previous studies suggest that children's understanding of surprise is belief-based (e.g., Hadwin & Perner, 1991; MacLaren & Olson, 1993; Wellman & Banerjee, 1991; Wellman & Bartsch, 1988). Further, participants in our experiments correctly anticipated what the characters

believed they would get. Therefore, it is perhaps puzzling that our belief prompts did not improve children's surprise judgments. Why was this prompt ineffectual? One possibility is that although children as young as age 4 use beliefs to *explain* surprise (e.g., Wellman & Banerjee, 1991), they might not use beliefs to *infer* surprise until later. The most careful study of children using belief to infer surprise found that they only started making these inferences at age 7, and that younger children instead used ignorance to infer surprise (Ruffman & Keenan, 1996). This could explain why our belief prompts were ineffectual.

Although we only investigated children's ability to use probability to infer surprise, they might also use probability to infer other emotions. For example, anyone would be happy about winning a contest; however, someone who wins a contest that 100 people entered might be happier and more excited than someone who wins a contest that 5 people entered. Similarly, losing a contest that 5 people entered would be more disappointing than losing a contest that 100 people entered – the outcome is the same, but the probability of the outcome occurring changes the degree of emotion experienced. Future research can examine whether probability also underlies children's understanding of emotions besides surprise. If children do use probability to infer these other emotions, this would further suggest that theories of emotion attribution should be expanded to acknowledge the role of probability.

Conclusion

Our findings are the first to show that children consider probability when attributing surprise. The findings also provide evidence for a developmental shift in children's ability to integrate their understandings of probability and surprise. Together, our studies advance knowledge of how children understand surprise, how they attribute emotions more generally, and how they use probability to make social inferences.

References

- Abelson, R. P. (1981). Psychological status of the script concept. *American Psychologist*, 36(7), 715-729. doi: 10.1037/0003-066X.36.7.715
- Barden, R. C., Zelko, F. A., Duncan, S. W., & Masters, J. C. (1980). Children's consensual knowledge about the experiential determinants of emotion. *Journal of Personality and Social Psychology*, 39(5), 968-976. doi: 10.1037/0022-3514.39.5.968
- Bartsch, K., & Estes, D. (1997). Children's and adults' everyday talk about surprise. *British Journal of Developmental Psychology*, 15(4), 461-475. doi: 10.1111/j.2044-835X.1997.tb00741.x
- Carlson, S. M. (2005). Developmentally sensitive measures of executive function in preschool children. *Developmental Neuropsychology*, 28(2), 595-616. doi: 10.1207/s15326942dn2802_3
- Carlson, S. M., & Moses, L. J. (2001). Individual differences in inhibitory control and children's theory of mind. *Child Development*, 72(4), 1032-1053. doi: 10.1111/1467-8624.00333
- Carlson, S. M., & Wang, T. S. (2007). Inhibitory control and emotion regulation in preschool children. *Cognitive Development*, 22(4), 489-510. doi: 10.1016/j.cogdev.2007.08.002
- Denison, S., Bonawitz, E., Gopnik, A., & Griffiths, T. L. (2013). Rational variability in children's causal inferences: The sampling hypothesis. *Cognition*, 126(2), 285-300. doi: 10.1016/j.cognition.2012.10.010
- Denison, S., Konopczynski, K., Garcia, V., & Xu, F. (2006). Probabilistic reasoning in preschoolers: Random sampling and base rate. In R. Sun & N. Miyake (Eds.), *Proceedings of the 28th annual conference of the Cognitive Science Society* (pp. 1216–1221). Florence, KY: Psychology Press.

- Denison, S., Reed, C., & Xu, F. (2013). The emergence of probabilistic reasoning in very young infants: Evidence from 4.5-and 6-month-olds. *Developmental Psychology*, 49(2), 243-249. doi: 10.1037/a0028278
- Giroto, V., Fontanari, L., Gonzalez, M., Vallortigara, G., & Blaye, A. (2016). Young children do not succeed in choice tasks that imply evaluating chances. *Cognition*, 152, 32-39. doi: 10.1016/j.cognition.2016.03.010
- Gopnik, A. & Meltzoff, A. N. (1997). *Words, thoughts, and theories*. Cambridge, MA: MIT Press.
- Hadwin, J., & Perner, J. (1991). Pleased and surprised: Children's cognitive theory of emotion. *British Journal of Developmental Psychology*, 9(2), 215-234. doi: 10.1111/j.2044-835X.1991.tb00872.x
- Harris, P. L., de Rosnay, M., & Pons, F. (2016). Understanding emotion. In Barrett, L. F. , Lewis, M., & Haviland-Jones, J. M.(Eds.), *Handbook of emotions* (293-306). Guilford Press.
- Harris, P. L., Johnson, C. N., Hutton, D., Andrews, G., & Cooke, T. (1989). Young children's theory of mind and emotion. *Cognition & Emotion*, 3(4), 379-400. doi: 10.1080/02699938908412713
- Harris, P. L., Olthof, T., Terwogt, M. M., & Hardman, C. E. (1987). Children's knowledge of the situations that provoke emotion. *International Journal of Behavioral Development*, 10(3), 319-343. doi: 10.1177/016502548701000304
- Kushnir, T., Xu, F., & Wellman, H. M. (2010). Young children use statistical sampling to infer the preferences of other people. *Psychological Science*, 21(8), 1134-1140. doi: 10.1177/0956797610376652

- Lagattuta, K. H. (2005). When you shouldn't do what you want to do: Young children's understanding of desires, rules, and emotions. *Child Development, 76*(3), 713-733. doi: 10.1111/j.1467-8624.2005.00873.x
- Lagattuta, K. H. (2008). Young children's knowledge about the influence of thoughts on emotions in rule situations. *Developmental Science, 11*(6), 809-818. doi: 10.1111/j.1467-7687.2008.00727.x
- Ma, L., & Xu, F. (2011). Young children's use of statistical sampling evidence to infer the subjectivity of preferences. *Cognition, 120*(3), 403-411. doi: 10.1016/j.cognition.2011.02.003
- MacLaren, R., & Olson, D. (1993). Trick or treat: Children's understanding of surprise. *Cognitive Development, 8*(1), 27-46. doi: 10.1016/0885-2014(93)90003-N
- Maguire, R., Maguire, P., & Keane, M. T. (2011). Making sense of surprise: An investigation of the factors influencing surprise judgments. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*(1), 176-186. doi: 10.1037/a0021609
- Rieffe, C., Terwogt, M. M., & Cowan, R. (2005). Children's understanding of mental states as causes of emotions. *Infant and Child Development, 14*(3), 259-272. doi: 10.1002/icd.391
- Ronfard, S., & Harris, P. L. (2014). When will Little Red Riding Hood become scared? Children's attribution of mental states to a story character. *Developmental Psychology, 50*(1), 283-292. doi: 10.1037/a0032970
- Ruffman, T., & Keenan, T. R. (1996). The belief-based emotion of surprise: The case for a lag in understanding relative to false belief. *Developmental Psychology, 32*(1), 40-49. doi: 10.1037/0012-1649.32.1.40
- Russell, J. A. (1990). The preschooler's understanding of the causes and consequences of emotion. *Child Development, 61*(6), 1872-1881. doi: 10.2307/1130843

- Scott, R. M. (2017). Surprise! 20-month-old infants understand the emotional consequences of false beliefs. *Cognition*, 159, 33-47. doi: 10.1016/j.cognition.2016.11.005
- Skerry, A. E., & Spelke, E. S. (2014). Preverbal infants identify emotional reactions that are incongruent with goal outcomes. *Cognition*, 130(2), 204-216. doi: 10.1016/j.cognition.2013.11.002
- Téglás, E., Girotto, V., Gonzalez, M., & Bonatti, L. L. (2007). Intuitions of probabilities shape expectations about the future at 12 months and beyond. *Proceedings of the National Academy of Sciences*, 104(48), 19156-19159. doi: 10.1073/pnas.0700271104
- Teigen, K. H., & Keren, G. (2003). Surprises: low probabilities or high contrasts?. *Cognition*, 87(2), 55-71. doi: 10.1016/s0010-0277(02)00201-9
- Wellman, H. M., & Banerjee, M. (1991). Mind and emotion: Children's understanding of the emotional consequences of beliefs and desires. *British Journal of Developmental Psychology*, 9(2), 191-214. doi: 10.1111/j.2044-835X.1991.tb00871.x
- Wellman, H. M., & Bartsch, K. (1988). Young children's reasoning about beliefs. *Cognition*, 30(3), 239-277. doi: 10.1016/0010-0277(88)90021-2
- Wellman, H. M., & Woolley, J. D. (1990). From simple desires to ordinary beliefs: The early development of everyday psychology. *Cognition*, 35(3), 245-275. doi: 10.1016/0010-0277(90)90024-E
- Widen, S. C., & Russell, J. A. (2010). Children's scripts for social emotions: Causes and consequences are more central than are facial expressions. *British Journal of Developmental Psychology*, 28(3), 565-581. doi: 10.1348/026151009X457550d

- Widen, S. C., & Russell, J. A. (2010). Young children's understanding of others' emotions. In Lewis, M., Haviland-Jones, J. M., & Barrett, L. F. (Eds.), *Handbook of emotions* (348-363). Guilford Press.
- Widen, S. C., & Russell, J. A. (2011). In building a script for an emotion, do preschoolers add its cause before its behavior consequence?. *Social Development*, 20(3), 471-485. doi: 10.1111/j.1467-9507.2010.00594.x
- Xu, F., & Garcia, V. (2008). Intuitive statistics by 8-month-old infants. *Proceedings of the National Academy of Sciences*, 105(13), 5012-5015. doi: 10.1073/pnas.0704450105