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"Yay! Yuck!" toddlers use others' emotional responses to reason about hidden objects

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ABSTRACT

Young children show sensitivity to others' emotions, discriminating between facial expressions and using them to help guide their behavior. Beyond providing information about how others are feeling, emotional expressions also can support inferences about the non-social world. Here, in four experiments, we investigated 18- to 28-month-old children's ability to use others' emotional responses to reason about physical objects. We found that 24- to 26-month-old children successfully used an agent's incongruent emotional responses ("Yay! Yuck!"), but not congruent emotional responses ("Yay! Wow!") to infer the presence of multiple hidden objects (Experiment 1). When two different agents produced the incongruent emotional responses, children did not infer that multiple objects must be present (Experiment 2), implicating early recognition that different people can have different emotional reactions towards the same entity. Younger, 20-month-old children failed to use incongruent emotional responses to make inferences about hidden objects (Experiment 3), although they succeeded at using contrasting words in an otherwise identical task ("A blick! A fep!"; Experiment 4). These results show that young children can use other people's emotional responses to reason about the physical world—an ability that develops in the second year of life.

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Humans are social learners—in every society, people use the actions and words of others to master new skills, acquire new ideas, and make better decisions (Fawcett & Liszkowski, 2015; Feinman, 1982). But what the people around us say and do is not the only source of valuable social information. Observing others' emotional responses, such as their facial expressions and vocalizations, also equips us with critical knowledge, and can do so immediately and irrespective of the language one speaks. A quick glance can tell us whether others think a new food is delicious or disgusting, or whether an impending action is safe or risky. Importantly, using emotional expressions in this way requires recognizing that emotions operate differently than other kinds of socially relevant information. For example, whereas two people will typically use the same word to refer to an object, they can have very different and even opposing emotional reactions to it. In contrast, a given person's emotional reaction to an object at one point in time often, but not always, predicts their reaction to the same entity later on. Understanding when emotional responses can differ and when they are likely to be constant is an important ingredient for successful social learning. The present work examines the early development of this understanding, probing children's ability to use similarities versus differences in emotional responses to make inferences about physical objects under conditions of epistemic uncertainty.

Early attention to emotion

Past research suggests that the drive to attend to emotion information is present from the start of life (see Ruba and Pollak, 2020 for a review). Newborns can discriminate between happy, sad, and surprised facial expressions produced by a live experimenter (Field et al., 1982; but see also Addabbo et al., 2018). By 5-months, infants can discriminate emotions in videos of multiple different individuals if provided both facial and vocal information, and by 7-months, they can discriminate different individuals' emotions using facial expressions alone (Caron et al.,1988). Infants also prioritize the processing of some emotions in particular. For example, infants as young as 3 months old show enhanced detection of fearful faces compared to happy ones (Bayet et al., 2017).

Attending to emotional responses is vital because young children use the differences between these responses to inform their decisions. For example, infants on the edge of an apparent drop-off avoided the cliff if they saw a caregiver express fear or anger, whereas they were more likely to attempt to cross if the caregiver expressed a positive emotion (Sorce et al., 1985). Fifteen- and 18-month old infants were less likely to imitate an action if they had previously seen an adult complete that action and then express negativity, compared to positivity or neutrality (Repacholi, 2009). Similarly, infants avoid toys and strangers towards which their caregivers expressed negativity (Boccia & Campos, 1989; Walden & Ogan, 1988; see Walle et al., 2017 for a review), even when the emotion-eliciting stimulus was not visible. Repacholi (1998) found that when an adult looked into one box and expressed happiness, and looked into another box and expressed disgust, infants preferentially searched the box containing the object that had apparently elicited happiness. And Mumme and Fernald (2003) found that 12-, but not 10-month-old infants who saw a recording of an agent reacting negatively to a novel object subsequently avoided the object in real life.

In addition to using emotional responses to decide what to approach or avoid and which actions to engage in, infants also can make inferences about the world using their knowledge of when people tend to feel specific emotions. For example, in research by Wu and colleagues (2017), 12- to 17-month-old infants saw an experimenter look inside a box and say either "Mmmm!" or "Awww!". When infants reached into the box they found either a toy strawberry or a toy puppy. If they found the puppy, infants continued to search the box longer if they had just heard "Mmmm!" (as though reasoning that the experimenter must have been responding to something other than the puppy). When infants found the strawberry, they continued searching longer if they had heard "Awww!" (see also Wellman, Phillips, & Rodriguez, 2000 for evidence with toddlers). This early knowledge of which entities tend to elicit which emotional responses also extends beyond simple objects to actions. By 12 months infants expect that when someone achieves a goal they will respond positively, not negatively (Skerry & Spelke, 2014), and that prosocial actions (like sharing a toy) are associated with positive rather than negative emotional responses from others (Reschke et al., 2017).

Abstract properties of emotional expressions

The above findings show that from early in life, children know quite a bit about specific emotional expressions, including that negative emotional expressions can signal danger, that positive events elicit positive expressions, and that certain objects are linked to particular emotional responses. This knowledge about specific emotions (e.g., fear, positivity) helps infants form predictions and act effectively. But adults also have a more flexible understanding of emotions—understanding that is not tied to any one emotion in particular. An important component of this understanding is the recognition that a person is unlikely to express two contrary emotional expressions towards the same stimulus at the same time. For example, I am unlikely to emote both positively and negatively to a single experience of tasting licorice. And although you might not know whether I like licorice or dislike it, you probably expect that both of these are not simultaneously true. Of course, it is possible to feel mixed emotions, but evidence suggests a more protracted developmental trajectory for understanding complex emotional blends. Children are unlikely to report experiencing mixed emotions until around 8 years of age (Larsen et al., 2007), and come to recognize mixed emotions in others at around the same time (Harter & Buddin, 1987). Kestenbaum and Gelman (1995) observed some partial understanding of mixed emotions between 3 and 5 years, such that by age 4 children can recognize faces as expressing more than one emotion; however, these younger children had difficulty applying this understanding to scenarios in which characters might be feeling multiple emotions at once (see Walle & Campos, 2014, for evidence that 19-month old infants may detect feigned emotions, as when a person finds a food item disgusting but pretends to enjoy it).

Importantly, despite the fact that it is rare for a person to express emotions with opposite valences towards a single stimulus, two different people can easily do so. For instance, I can react negatively toward licorice, and you can react positively. Put differently, emotional responses do not necessarily generalize– the way I react towards something does not reliably predict the way you will react towards it (Repacholi, Meltzoff, Hennings, & Ruba, 2016; Repacholi, Meltzoff, Toub, & Ruba, 2016). Infants recognize the lack of generalization across agents in other domains. They know that two people can have different goals (Buresh & Woodward, 2007; Luo et al., 2017), preferences (Egyed et al., 2013; Henderson & Woodward, 2012; Liberman et al., 2016; Vaish et al., 2015), and degree of reliability in their responses (Chow et al., 2008). By age 2, children extend this understanding to preferences that conflict with their own, offering an adult a food towards which the adult had previously expressed happiness, even if it was a food the child themselves dispreferred (Repacholi & Gopnik, 1997; but see also Ruffman et al., 2018). By 5 years, children understand that two people can have different emotional reactions to the same event, depending on what their expectations were (i.e., whether the outcome exceeded or fell short of what they had predicted) (Asaba et al., 2019); however, when this understanding emerges remains unclear.

The present work

When do children exhibit a general understanding of conflicting emotional responses—recognizing that people do not tend to produce incongruent emotional expressions towards a single entity, but that two people may respond to a single entity in emotionally opposing ways? In the present work we addressed this question by asking whether infants and young toddlers can use their understanding of others' emotional responses to make inferences about hidden aspects of the world. In particular, we probed children's use of emotional cues to solve the problem of object individuation—that is, determining how many objects are present in an ambiguous scene. If young children recognize that an observer is unlikely to feel two conflicting emotions towards a single stimulus, then seeing someone produce two different emotional responses should lead them to infer that at least two separate objects are present. In contrast, seeing two individuals express two different emotional responses should not license the same inference.

Although it remains unknown whether infants or young children can use their understanding of emotions to individuate in this way, infants engage in similar reasoning using their knowledge of the properties of language. Xu (2002) demonstrated that 9- and 12-month-old infants who observed an adult peer into a box and utter two distinct novel labels (e.g., "A toma!" "A fendle!") inferred that more than one object must be present, even when the objects were never seen together. Since infants could not have known the meanings of "toma" or "fendle," they must have used a higher order expectation that two words do not typically refer to a single object. In contrast, Xu found that, under the same conditions, infants did not individuate when they heard two incongruent emotional responses (e.g., "ah" and "ewy") (see also Xu et al., 2005). Thus, although sensitivity to emotions is present from the earliest days, and although infants make inferences using specific emotional responses from their first year of life, it is an open question when in development a more abstract understanding of emotions emerges. Xu's (2002) findings suggest that it may be after the age of 12 months.

Here we investigated the ability of older infants and toddlers to recognize that incongruent emotional responses signal the presence of numerically distinct objects. In Experiment 1 and 3, we asked whether 26- and 20-month-old children can use incongruent responses (e.g., positivity and disgust) to trigger the tokening of multiple object representations. In Experiment 2, we asked whether children recognize that incongruent emotional responses produced by two different agents do not necessarily implicate the presence of multiple objects. Finally, in Experiment 4, we tested 20-month-olds' ability to use verbal labels to individuate objects, so that we could compare infants' ability to individuate using words versus emotional responses.

Experiment 1

In Experiment 1 we asked whether young toddlers can use another person's emotional responses to reason about the number of objects in an ambiguous scene. Children watched an experimenter peer into an opaque box and produce two emotional responses. On some trials the responses were emotionally congruent (e.g., "Yay! Wow!" and "Eew! Yuck!") whereas on other trials they were incongruent (e.g., "Yay! Yuck!" and "Eew! Wow!"). Children then saw the experimenter reach into the box and retrieve one object (whose identity remained hidden). The dependent measure was how long children then searched the box for any remaining objects. We hypothesized that if children recognized that a single object is unlikely to elicit two incongruent emotional responses from one observer, they should search longer on Incongruent Emotion trials than Congruent Emotion trials.

Method

Participants

Sixteen children between 22- and 29-months-old participated (M_{age} = 26.43 months, SD = 1.22, three girls). This age range was selected on the basis of previous work examining young toddlers' ability to make emotion-relevant inferences (Wu et al., 2017). Fourteen children were identified by their parents as White, one as Black, and one as Asian. Four additional children were tested but excluded from data analysis due to technical error (1), refusal to search during familiarization trials (1), or parent interference (2). Sample size was chosen based on previous studies that used the manual search method (e.g., Barner et al., 2007; Feigenson & Carey, 2005; Stahl & Feigenson, 2018), and N = 16 was our designated stopping rule for all four experiments. A post-hoc power analysis using G*Power (Faul et al., 2007) verified that our sample size was adequate to detect a difference between searching in Incongruent and Congruent Emotion trials (our primary comparison of interest) using a two-tailed paired samples t-test. Assuming a large effect size (Cohen's d = 0.80) with .05 alpha, power was .85.

All children received a small gift for their participation (e.g., T-shirt, stuffed animal, book). This study was conducted with approval from the Johns Hopkins University Institutional Review Board (Approval #HIRB00000590, "Short-term memory limits in infancy").

Stimuli

Children searched for toys hidden in a black foam core box (40.5 × 25 × 12.7 cm) whose front contained an opening (13 × 8.5 cm) covered by yellow spandex. The spandex had a slit across its width so that children could reach into the box without seeing inside. The back of the box contained an opening (17.8 × 10 cm) covered by a black felt flap.

Children saw stimulus objects from familiar categories on one familiarization trial and all filler trials, and saw an unfamiliar novel object on a second familiarization trial. Unfamiliar novel objects were also used during test trials, but children did not actually see these objects (see *Test Trials* for further explanation). The familiar-category objects were a block, a toy strawberry, a toy pizza slice, a toy dog, and a toy cat. The novel objects were a plastic doll's dress, a twisted foam hair curler, a plastic fried shrimp, half of a swim goggle, and a blue toothbrush holder. All objects were similar in size.

After objects were retrieved from the search box they were placed into either a smaller box or a bucket, depending on trial type (see below). The boxes (15.24 × 15.24 × 14.99 cm) were colorfully decorated and made of cardboard; the buckets were solid in color and varied in size.

Procedure

Familiarization. Children sat in a high chair at a table across from the experimenter. They were first familiarized to the search box, which the experimenter shook to indicate that it was empty. The experimenter then brought out the toy block, placed it atop the box, and said, "See this toy? It's going in my toy box. In we go!" She picked up the block and inserted it through the spandex opening in the front of the box. She then said, "Can you get it?" and pushed the box forward. Once children had reached in and retrieved the block, the experimenter said, "Can I see it?", took the block, and pulled the search box away. The experimenter then repeated this practice hiding event with the plastic doll's dress plus the block, in order to demonstrate that sometimes more than one object could be inside the box. The two familiarization trials were identical across all experiments for all children. After familiarization was complete, children were tested with four test trials and four filler trials, in alternation.

Test Trials. On each test trial, the experimenter brought out a bucket and said, "See this? It's empty!", turning it over to demonstrate. She then said, "Can you help me find things to put in my bucket?" and brought out the search box, which had been pre-baited with an object. The experimenter said, "I'll go first! Let's see what's in here!" She pulled down the spandex with one hand and peered into the box, her face visible to children. Critically, children saw that the experimenter could see into the box, even though they themselves could not. As the experimenter looked into the box she produced two utterances, 3 s apart. On Congruent Emotion trials the two utterances were aligned in their emotional valence (either "Yay! Wow!" or "Eew! Yuck!") and on Incongruent Emotion trials they were misaligned (either "Eew! Wow!" or "Yay! Yuck!"). The experimenter's facial expressions matched these utterances: smiling and widening her eyes when producing a positive utterance, wrinkling her nose and turning down the corners of her mouth when producing a negative utterance.

Then the experimenter reached into the box and retrieved the object that had been pre-hidden. Holding it in her closed fist, she showed children as she dropped the object into the bucket, where it made an audible *clink*. Children could not see the retrieved object's identity on the test trials in order to ensure that they could not use this information to infer whether another object remained in the box (e.g., could not have decided that an appealing object could not have prompted the experimenter to say "Eew! Yuck!" and so searched for another object—an ability explored by Wu et al., (2017). Here, we instead wanted to know whether, without knowing anything about object identity, children have the more abstract expectation that incongruent emotional responses pick out numerically distinct objects. We used novel objects on the test trials, even though the task was designed so that these objects would not be seen, just in case an object was inadvertently revealed during the presentation. The bucket containing the retrieved object was positioned so that children could not see inside it, and none of the children tested were judged to have seen any of the test objects.

Once she had dropped the retrieved object into the bucket and moved the bucket out of reach, the experimenter said, "Your turn!" and held the search box in place for children to reach into if they wanted. As she did this she lowered her head to avoid providing any cues that might influence children's behavior. Children's searching was recorded for the 10 s that followed. If children were still searching at the 10-s mark, the experimenter waited with her head down until children had removed their hand(s) from the box before taking the box from the table and ending the trial. Once the trial was over, the experimenter said, "Let's play again!", and the next trial began (see Fig. 1 for schematic of the test trial procedure).

Schematic of the test trial procedure used in Experiments 1 and 3

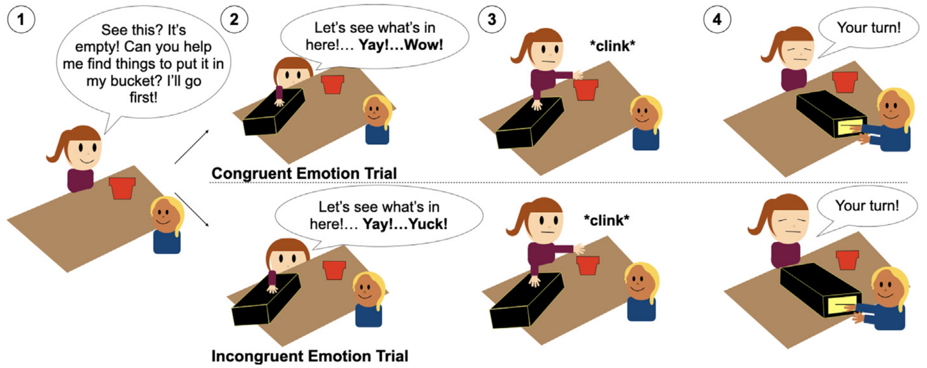

Fig. 1. Schematic of the test trial procedure used in Experiments 1 and 3.

Children received two Congruent Emotion and two Incongruent Emotion test trials in alternation (interleaved with filler trials; see below). One Congruent Emotion trial contained two positive utterances ("Yay! Wow!") and the other contained two negative utterances ("Eew! Yuck!"). One Incongruent Emotion trial presented the positive emotion first, and the other presented the negative emotion first; order of these was fully counterbalanced across children, resulting in eight possible test trial orders.

Filler Trials. Interleaved with the four test trials were four filler trials designed to maintain children's motivation to participate. Because on test trials children themselves never retrieved any objects from the box, we were concerned that they would lose interest in the task. The filler trials were included to counteract this possibility, because on filler trials children always successfully retrieved a toy from the box. On each filler trial the experimenter said, "It's your turn!", brought out the search box, peered into it through the spandex slit in the front, and produced two emotional utterances. Children were allowed to reach into the box and retrieve an object. On two of the filler trials children heard "Aww! Cute!" and retrieved a toy animal, and on the other two they heard "Yum! Mmm!" and retrieved a toy food item. Hence the utterances in each filler trial were always emotionally congruent, and always involved emotions that differed from those in the test trials (see Wu et al., 2017). Once children had retrieved the object, the experimenter said, "Can you put it in here?" and pointed to the empty smaller box. After children had put the object in the box, the experimenter put on the lid and said, "Can you give this to [e.g., Mommy or Daddy]?" Children gave the box to their caregiver, who placed it on the floor out of view. No searching was measured on filler trials.

Coding. Test trials were coded frame by frame from video by two experienced coders who were naive to trial type (Congruent or Incongruent Emotion). Children were counted as searching when one or both hands were inserted through the front of the box past the second knuckle. If children became disengaged from the task while their hand was inside (e.g., resting their hand in the box but turning around to engage with their caregiver), or if they became interested in grasping the spandex, this was not counted as searching. If children were still actively searching at the 10-s mark, they were coded as searching until they removed their hand(s) from the box; as such, search times could be longer than 10 s. Intercoder reliability was high: intraclass coder coefficient (ICC) =.93, p <.001.

Results

Our key question was whether children would search the box longer for a remaining object(s) after hearing two emotionally incongruent utterances, compared to two different but emotionally congruent utterances. We found that on Incongruent Emotion trials, toddlers searched for an average of 5.8 s (SD = 3.46 s); on Congruent Emotion trials they searched for an average of 3.76 s (SD = 1.93 s). Fourteen out of the 16 infants searched longer on Incongruent Emotion trials, two-tailed binomial

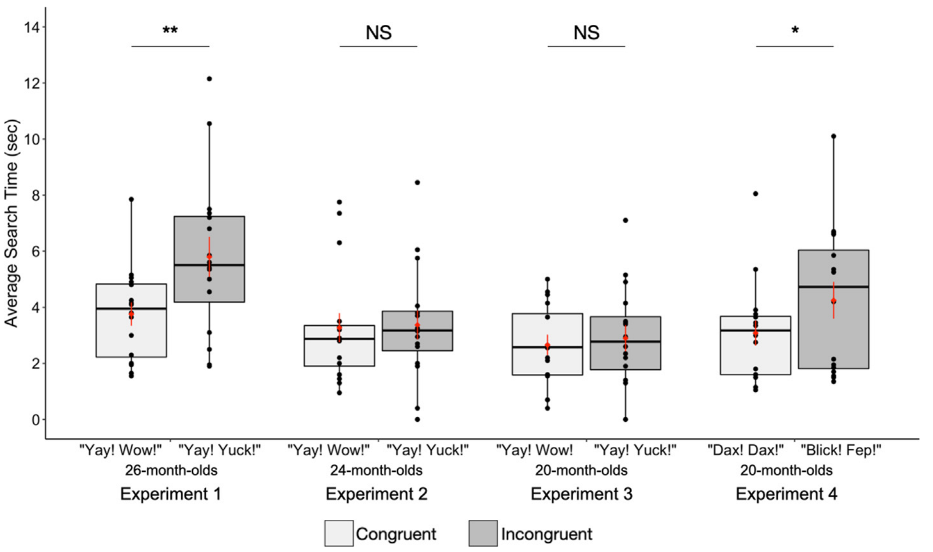

Fig. 2. Results of Experiments 1–4. Black dots represent individual children's average search times collapsed within each Trial Type. Red dots represent means; red lines represent SEM; boxes represent 95% confidence intervals. *p < 0.05, **p < 0.01.

test: p =.004, 95% CI [0.62, 0.98]. A full-factorial 2 (Trial Type: Congruent vs. Incongruent Emotion) $\times$ 2 (Trial Pair: First Pair of Congruent and Incongruent Trials vs. Second Pair) $\times$ 2 (First Trial Type: Congruent vs. Incongruent Emotion) $\times$ 2 (First Emotion: Positive vs. Negative) repeated measures analysis of variance (ANOVA) revealed a significant effect of Trial Type, $F(1,12)$ = 10.82, p =.006, η^2 =.15. A paired samples t-test confirmed that children searched longer on Incongruent Emotion trials than Congruent Emotion trials, $t(15)$ = 3.58, p =.003, d = 0.89, 95% CI [0.82, 3.25] (Fig. 2). There was no effect of Trial Pair, $F(1,12)$ = 1.48, p = 0.25, η^2 =.02, First Trial Type, $F(1,12)$ = 0.93, p =.35, η^2 =.04, or First Emotion, $F(1,12)$ = 0.64, p =.44, η^2 =.03, although there was an interaction between Trial Pair and First Emotion, $F(1,12)$ = 5.58, p =.036, η^2 =.08. This interaction was driven by children who heard a positive emotion first searching longer in the first block of trials than the second, regardless of trial type (Congruent or Incongruent Emotion).

Experiment 2

The results of Experiment 1 suggest that 2-year-old children can use another person's emotional responses to infer how many objects are present in an ambiguous scene. When an experimenter produced two emotionally incongruent utterances (e.g., "Yay! Yuck!"), but only retrieved a single object, children continued to search the box longer than when the experimenter had produced two congruent utterances (e.g., "Wow! Yay"). This suggests that by about 26 months of age, children recognize that a person is unlikely to produce two incongruent emotional responses to a single object. That is, children can use emotions to individuate objects.

Next, we asked whether children respond differently to incongruent emotional responses if the responses are produced by two different agents. Previous findings suggest that by 18 months, toddlers understand that people can have preferences that differ from their own (Repacholi & Gopnik, 1997), and by 9 months infants understand that two people can have different goals (Buresh & Woodward, 2007; Luo et al., 2017). Further, by 2 years of age children expect object labels, but not preferences, to be consistent across individuals (Henderson & Graham, 2005). In Experiment 2, we asked whether toddlers also understand that emotional responses do not necessarily generalize across individuals. As in Experiment 1, we measured children's searching after they had heard two emotionally incongruent utterances and saw only one object retrieved. However, this time the emotional utterances were produced by two different social agents.

This design had the additional advantage of ruling out an alternative explanation of the results of Experiment 1. Rather than relying on a higher-order expectation that people do not tend to experience conflicting emotions towards a single stimulus, children could have used a more basic feature of the experimenter's utterances and facial expressions to motivate their searching. If Incongruent Emotion trials were simply more arousing because they contained a greater range of emotion than Congruent Emotion trials, this might have boosted children's activity in general, resulting in longer searching on those trials. On this account, children would have no specific commitment that a person is unlikely to have incongruent emotional responses to a single object. Rather, more emotional range would just yield more behavior (in this case, more searching).

We tested this possibility in Experiment 2. If children's object individuation in Experiment 1 depended on the assumption that a single individual is unlikely to produce two conflicting emotional responses towards a single object, then the results of Experiment 2 should differ from those of Experiment 1. Alternatively, if children's behaviors were simply heightened overall by experiencing a wider range of emotional utterances and facial expressions, they should again search longer on Incongruent than Congruent Emotion trials.

Method

Participants

Sixteen children between 22- and 29-months-old participated (M_{age} = 24.18 months, SD = 1.90, seven girls). Thirteen children were identified by their parents as White, two as Black or African American, and one as Asian. Two additional children were tested but excluded from the final data analysis due to parent interference.

Stimuli

The stimuli were as in Experiment 1, with the addition of two stuffed animals: a light brown dog and a pink pig (each 16.5 cm tall).

Procedure

The procedure was similar to that of Experiment 1, except that the two stuffed animals were made to peer into the search box and produce the stimulus utterances, rather than the experimenter (Fig. 3). Two animals were used rather than two experimenters because we were concerned that introducing an additional person into the small testing room would distract children, and because previous work from our lab has successfully used toy agents within the context of the manual search procedure (Stahl & Feigenson, 2018).

Test Trials. After familiarization with the search box, the experimenter brought out the dog and pig stuffed animals and placed them on the table facing children. The experimenter said, "These are my friends! This is Mr. Dog and this is Mr. Pig. They're going to help us today!" Then, as in Experiment 1, the experimenter brought out a bucket, showed that it was empty, and asked whether children would help find things in the box to put in the bucket. Then the experimenter said, "Mr. Dog is going to look inside first, and then Mr. Pig." The order of animals was counterbalanced across children. The experimenter said, "Let's see what's in here!".

She made the dog peek through the slit in the spandex at the front of the search box, and said, "Mr. Dog says, '(e.g., Yay)!'", with her facial expression matching that of the utterance. The experimenter then put the dog back on the table and made the pig peer into the box, saying, "Mr. Pig says, '(e.g., Wow or Eew)'!'" The experimenter then put the pig back on the table, reached into the box and retrieved an object just as in Experiment 1, making sure to conceal its identity in her closed hand before dropping it audibly into the bucket. As in Experiment 1, children were then allowed to search the box for any remaining objects for 10 s before the trial ended. As in Experiment 1, children were tested with two Congruent Emotion trials ("Yay! Wow!" or "Eew! Yuck!") and two Incongruent Emotion trials ("Yay! Yuck!" or "Eew! Wow!"), with order fully counterbalanced.

Filler Trials. Filler trials were as in Experiment 1, except that the dog and pig were made to peer into the box and produce the utterances, rather than the experimenter. Children heard, "Mr. Dog says, 'Aww!'...Mr. Pig says, 'Cute!'" and then retrieved a toy animal from the search box, or heard, "Mr. Dog

Schematic of the test trial procedure used in Experiment 2

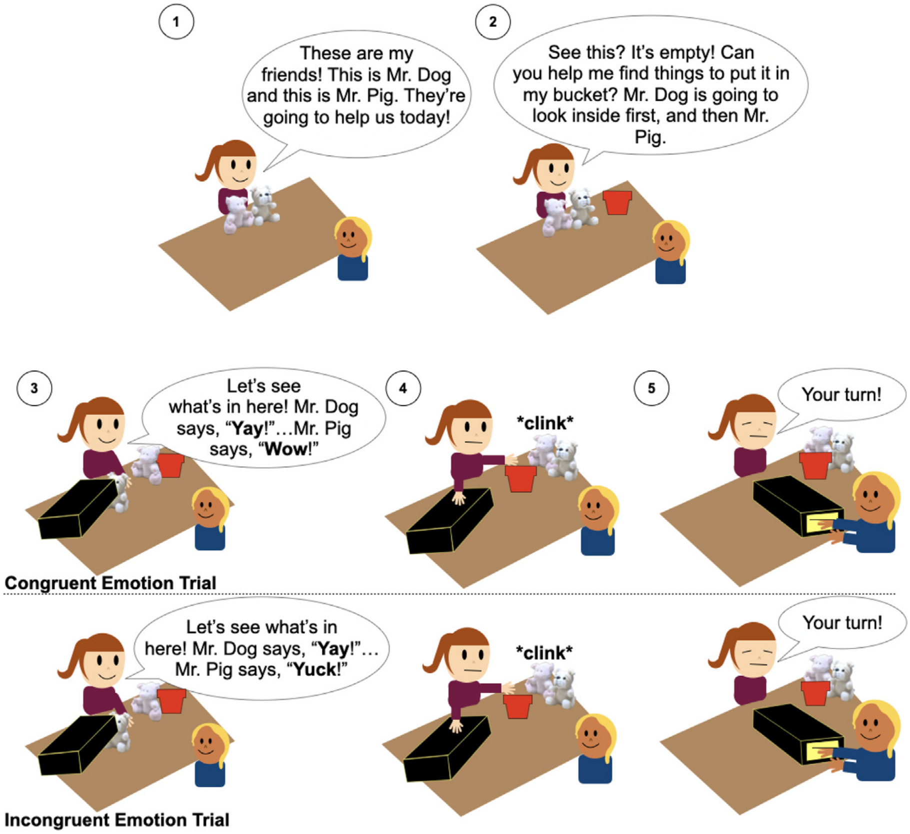

Fig. 3. Schematic of the test trial procedure used in Experiment 2.

says, 'Yum!'...Mr. Pig says, 'Mmm!'" and then retrieved a toy food item from the search box. As in Experiment 1, utterances were always emotionally congruent in the filler trials, and test trials and filler trials alternated.

Coding. Coding was as in Experiment 1. Intercoder reliability was high: ICC =.95, p <.001.

Results

On Incongruent Emotion trials toddlers searched for an average of 3.37 s (SD = 2.32 s); on Congruent Emotion trials they searched for an average of 3.27 s (SD = 2.33 s). Eight out of the 16 infants searched longer on Incongruent Emotion trials, two-tailed binomial test: p = 1.00, 95% CI [0.25, 0.75]. A full-factorial 2 (Trial Type: Congruent vs. Incongruent Emotion) $\times$ 2 (Trial Pair: First Pair of Congruent and Incongruent Trials vs. Second Pair) $\times$ 2 (First Trial Type: Congruent vs Incongruent Emotion) $\times$ 2 (First Emotion: Positive vs. Negative) repeated measures ANOVA revealed no significant effect of Trial Type, $F(1,12)$ = 0.001, p =.98, η^2 =.00. As predicted, children did not search longer on Incongruent Emotion trials than Congruent Emotion trials, $t(15)$ = 0.21, p =.83, d = 0.05, 95% CI [-0.90, 1.10] (Fig. 2). There were also no effects of Trial Pair, $F(1,12)$ = 1.25, p =.29, η^2 =.01, First Trial Type, $F(1,12)$ = 0.006, p =.94, η^2 =.00, or First Emotion, $F(1,12)$ = 0.002, p =.97, η^2 =.00, and no interactions between these, Fs < 4.09, ps >.07.

To ask whether children differed in performance across Experiments 1 and 2, we ran a 2 (Experiment: Experiment 1 vs. Experiment 2) × 2 (Trial Type: Congruent vs. Incongruent Emotion) × 2 (Trial Pair: First Pair of Congruent and Incongruent Trials vs. Second Pair) × 2 (First Trial Type: Congruent vs Incongruent Emotion) repeated measures ANOVA. This revealed a significant effect of Experiment, $F(1,28) = 4.80$, $p = .037$, $\eta^2 = .09$: toddlers searched longer overall in Experiment 1 compared to Experiment 2. We also observed a significant main effect of Trial Type, $F(1,28) = 8.07$, $p = .008$, $\eta^2 = .05$, qualified by a significant interaction between Experiment and Trial Type, $F(1,28) = 6.90$, $p = .014$, $\eta^2 = .04$. Critically, the difference in children's searching on Incongruent Emotion versus Congruent Emotion trials was greater in Experiment 1 than Experiment 2. There were no other significant main effects or interactions, $Fs < 1.65$, $ps > .21$.

The mean age of children in Experiments 1 and 2 differed slightly due to random sampling of the children available in our recruitment database. To address the possibility that children in Experiment 2 failed to search longer on Incongruent Emotion trials because they were slightly younger than children in Experiment 1, we ran additional exploratory analyses on a subset of participants across the two experiments. We roughly equated the mean age of the two groups by constraining the age range from 23-months to 27-months rather than 22-months to 28-months, removing the most extreme ages from each experiment. Nine children from Experiment 1 (M_{age}: 25.74 months) were compared to nine children from Experiment 2 (M_{age}: 24.38 months). Paired sample t-tests confirmed that children in Experiment 1 searched longer on Incongruent Emotion trials ($M = 6.16$ s, $SD = 2.62$ s) than Congruent Emotion trials ($M = 3.3$ s, $SD = 1.34$ s), $t(8) = 3.93$, $p < 0.01$, $d = 1.31$, 95% CI [1.18, 4.53], whereas children in Experiment 2 did not search longer on Incongruent Emotion trials ($M = 3.89$ s, $SD = 2.50$ s) than Congruent Emotion trials ($M = 3.47$ s, $SD = 2.42$ s), $t(8) = 0.55$, $p = .60$, $d = 0.18$, [-1.33, 2.16]. As an additional analysis, we conducted a median split by age of the children in Experiments 1 and 2, and conducted paired sample t-tests on the younger children in Experiment 1 (M_{age}: 25.60 months) and the older children in Experiment 2 (M_{age}: 25.71 months). Paired sample t-tests confirmed that the younger children in Experiment 1 searched longer on Incongruent Emotion trials ($M = 6.36$ s, $SD = 3.65$ s) than Congruent Emotion trials ($M = 3.34$ s, $SD = 1.75$), $t(7) = 3.76$, $p = 0.007$, $d = 1.33$, 95% CI [1.12, 4.92], whereas older children in Experiment 2 did not search longer on Incongruent Emotion trials ($M = 3.56$ s, $SD = 1.81$ s) than Congruent Emotion trials ($M = 3.33$ s, $SD = 1.91$ s), $t(7) = 0.27$, $p = .80$, $d = 0.10$, [-1.80, 2.26].

It is also unlikely that the difference in children's searching between Experiments 1 and 2 was driven by the introduction of the stuffed animals in Experiment 2. On Congruent Emotion trials, which we did not expect to differ across experiments, children searched similarly across Experiments 1 and 2, $t(30) = 0.732$, $p = 0.47$, $d = 0.26$, 95% CI [-0.87, 1.85], suggesting that they were not simply distracted by the stuffed animals. The finding that only searching on Incongruent Emotion trials differed across experiments, both overall, $t(30) = 2.75$, $p = .01$, $d = 0.97$, [0.62, 4.23] and in the age-matched sample identified by the median split analysis, $t(14) = 2.42$, $p = .03$, $d = 1.21$, [0.32, 5.28], suggests that it was specifically the pairing of emotional responses with agents that determined whether children inferred the presence of additional hidden objects in the box. Still, despite previous findings that infants readily engage with stuffed animals in the context of the manual search task, and that this does not negatively impact their reasoning about what might be hidden in the search box (e.g., Stahl & Feigenson, 2018), our results cannot rule out the possibility that children might have behaved differently in response to incongruent emotional responses by two human actors. As such, we interpret the findings of Experiment 2 with a note of caution.

Experiment 3

The combined results of Experiments 1 and 2 suggest that 2-year old children can use emotion cues to infer the number of objects in a scene. Children in Experiment 1 appeared to assume that one person was not producing two conflicting emotional responses to a single object. These children searched a box longer after hearing the experimenter produce two different emotional responses to the box's contents but finding only a single object, compared to after hearing the experimenter produce two different tokens of the same emotional response and finding a single object. Experiment 2 ruled out the possibility that this pattern was driven by the overall amount of emotional variation children heard.

When incongruent emotional responses were produced by two separate agents, children did not continue searching for a remaining object. Hence, by about 24–26 months, children seem to recognize that an individual tends to have a consistent emotional reaction to a particular object — but that different individuals can have different reactions to the same object. Moreover, children use this expectation to support inferences about things they cannot see.

When do children become capable of using emotion to solve the problem of object individuation? By 9-months old, infants can use the contrast between novel labels (e.g., "A dax!...A blick!") to infer the presence of numerically distinct objects (Xu, 2002). But at that same age, infants did not expect that two incongruent emotions (e.g., "Ah!...Ewy!") implicated the presence of multiple objects. The results of Experiment 1 above suggest that by 26 months, children can do this robustly. This leaves open the question of when the ability to use an agent's incongruent emotions to individuate objects comes online. In Experiment 3 we asked whether children younger than 2 years old can use emotional responses to individuate hidden objects.

Method

Participants

Sixteen children between 18- and 22-months-old participated (M_{age} = 19.62 months, *SD* = 0.83, 10 girls). Thirteen children were identified by their parents as White, one as Black, and two as Asian. Seven additional children were tested but excluded from the final data analysis due to parent interference (4) or refusal to search during familiarization trials (3).

Stimuli

The stimuli were as in Experiment 1.

Procedure

The procedure was as in Experiment 1 (see Fig. 1).

Coding. Coding was as in Experiments 1 and 2. Intercoder reliability was high: ICC =.92, p <.001.

Results

On the Incongruent Emotion trials, toddlers searched for an average of 2.90 s (*SD* = 2.33 s); on Congruent Emotion trials they searched for an average of 2.66 s (*SD* = 2.01 s). Eight out of the 16 infants searched longer on Incongruent Emotion trials, two-tailed binomial test: p = 1.00, 95% CI [0.25, 0.75]. A full-factorial 2 (Trial Type: Congruent vs. Incongruent Emotion) × 2 (Trial Pair: First Pair of Congruent and Incongruent Trials vs. Second Pair) × 2 (First Trial Type: Congruent vs Incongruent Emotion) × 2 (First Emotion: Positive vs. Negative Emotion) repeated measures ANOVA revealed no significant effect of Trial Type, $F(1,12)$ = 0.25, p =.62, η^2 =.00. Children in Experiment 3 did not search longer on Incongruent Emotion trials than Congruent Emotion trials, $t(15)$ = 0.64, p =.53, d = 0.16, 95% CI [-0.56, 1.05] (Fig. 2), suggesting that they were unable to use emotional responses as a means to individuate objects. There were no main effects or interactions observed, *Fs* < 3.52, *ps* >.09.

To ask whether younger and older children differed in their ability to use emotion to individuate, we compared the results of Experiments 1 and 3. A 2 (Experiment: Experiment 1 vs. Experiment 3) × 2 (Trial Type: Congruent vs. Incongruent Emotion) × 2 (Trial Pair: First Pair of Congruent and Incongruent Trials vs. Second Pair) × 2 (First Trial Type: Congruent vs Incongruent Emotion) repeated measures ANOVA revealed a significant main effect of Experiment, $F(1,28)$ = 10.70, p =.003, η^2 =.16, resulting from the older children in Experiment 1 (26-month-olds) searching longer overall than the younger children in Experiment 2 (20-month-olds). There was also a main effect of Trial Type, $F(1,28)$ = 10.62, p =.003, η^2 =.06, with children searching longer on Incongruent Emotion trials. However, this was qualified by a significant interaction between Experiment and Trial Type, $F(1,28)$ = 7.02, p =.013, η^2 =.04. The difference in children's searching on Incongruent Emotion versus Congruent Emotion trials was greater in Experiment 1 than Experiment 3.

To further examine possible effects of age, we conducted a linear regression on toddlers' search times using Age in months as a predictor variable. Difference scores were created by subtracting each

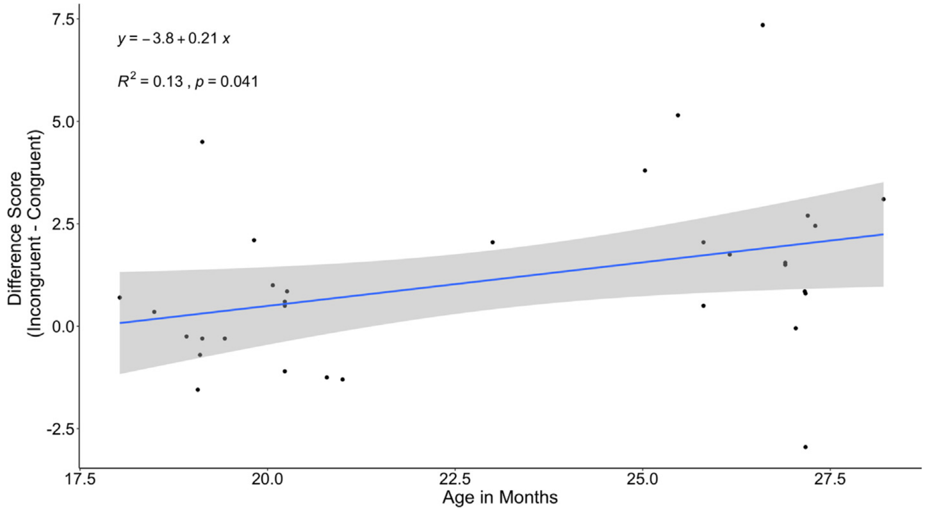

Fig. 4. Difference in Searching During Incongruent and Congruent Trials as a Function of Age. Black dots represent individual children's difference scores (average searching on Incongruent trials minus average searching on Congruent trials).

toddler's average searching on Congruent Trials from their average searching on Incongruent Trials, such that longer searching during Incongruent Trials would result in positive values, whereas longer searching during Congruent Trials would result in negative values. We found that Age significantly predicted toddlers' difference scores, R^2 = 0.13, $F(1, 30)$ = 4.577, p =.041 (Fig. 4), with longer searching on Incongruent trials increasing with age, β = 0.213. Thus, children appear to get better at using an agent's incongruent utterances to individuate hidden objects over the course of development.

Experiment 4

Together, the results of Experiments 1 and 3 suggest that children's ability to use emotional responses to individuate objects may develop between the ages of 20- and 26-months. Whereas the 2-year-olds in Experiment 1 succeeded at using incongruent emotional responses to infer the presence of a second hidden object, children younger than 2 years failed. Previous work suggests that this failure is unlikely to reflect a more general difficulty understanding the task, or trouble using auditory information to determine how many objects are present: children much younger than 2 years can use other types of non-visual information to individuate objects in a manual search task (Xu et al., 2005). Still, to make sure that, in the context of our stimuli and procedure, younger children could individuate using auditory contrasts that did not require an understanding of emotion, we tested a separate group of infants in Experiment 4. We asked whether 20-month-old children could use the contrast between novel nouns (e.g., "A blick! A fep!") to individuate, under conditions like those in Experiment 3. Based on previous work, we expected children to succeed (Balaban & Waxman, 1997; Xu, 2002; Xu et al., 2005).

Method

Participants

Sixteen children between 18- and 22-months-old participated (M_{age} = 19.79 months, SD = 1.09, 10 girls). Twelve children were identified by their parents as White, two as Black or African American, and two as Asian. Four additional children were excluded from the final data analysis due to parent interference (2) or refusal to search during familiarization (2). All of the children were reported by their parents to hear only English at home.

Stimuli

The object stimuli were as in Experiments 1 and 3.

Procedure

The procedure was as in Experiments 1 and 3, except that the test trial utterances contained novel labels instead of emotional responses (Fig. 5). On two test trials children observed the experimenter peering into the box and uttering two Congruent Labels (e.g., "Look! A dax!... A dax!"), and on two test trials they experienced the experimenter uttering two Incongruent Labels (e.g., "Look! A blick!... A fep!"). On the filler trials children heard familiar words and the labels were always congruent (e.g., "Look! A cat! A cat!"). The experimenter produced the same mildly positive emotional facial expression and prosody across all trials. As in Experiments 1–3, test and filler trials alternated.

Coding. Coding was as in Experiments 1–3. Intercoder reliability was high: ICC =.93, p <.001.

Results

On the Incongruent Label trials, toddlers searched for an average of 4.25 s (SD = 3.09 s); on Congruent Label trials they searched for an average of 3.08 s (SD = 2.25 s). Thirteen out of the 16 infants searched longer on Incongruent Emotion trials, two-tailed binomial test: p =.021, 95% CI [0.54, 0.96]. A full-factorial 2 (Trial Type: Congruent vs. Incongruent Label) × 2 (Trial Pair: First Pair of Congruent and Incongruent Trials vs. Second Pair) × 2 (First Trial Type: Congruent vs Incongruent Label) repeated measures ANOVA revealed a significant effect of Trial Type, $F(1,14) = 8.96$, p =.01, η^2 =.08. A paired samples t-test revealed that children searched longer on Incongruent Label trials than Congruent Label trials, $t(15) = 2.35$, p =.03, d = 0.59, 95% CI [0.11, 2.23] (Fig. 2). There were no effects of Trial Pair, $F(1,14) = 1.734$, p =.21, η^2 =.02, or First Trial Type, $F(1,14) = 0.25$, p =.63, η^2 =.00. The only other effect was a non-predicted interaction between Trial Pair and First Trial Type, $F(1,14) = 9.39$, p =.008, η^2 =.08. Children who heard incongruent labels first searched longer in the first pair of trials compared to the second.

To ask whether younger children's ability to individuate differed for incongruent labels compared to incongruent emotions, we compared the results of Experiments 3 and 4. A 2 (Experiment: Experiment 3 vs. Experiment 4) × 2 (Trial Type: Congruent vs. Incongruent Input) × 2 (Trial Pair: First Pair of Congruent and Incongruent Trials vs. Second Pair) × 2 (First Trial Type: Congruent vs. Incongruent Input) repeated measures ANOVA revealed no main effect of Experiment, $F(1,28) = 2.29$, p =.14, η^2 =.05: there was no difference in children's searching across experiments, overall. There was a main effect of Trial Type, $F(1,28) = 7.38$, p =.01, η^2 =.03 – toddlers searched longer during Incongruent trials, overall – and a main effect Trial Pair, $F(1,28) = 5.01$, p =.03, η^2 =.02 – toddlers searched longer during

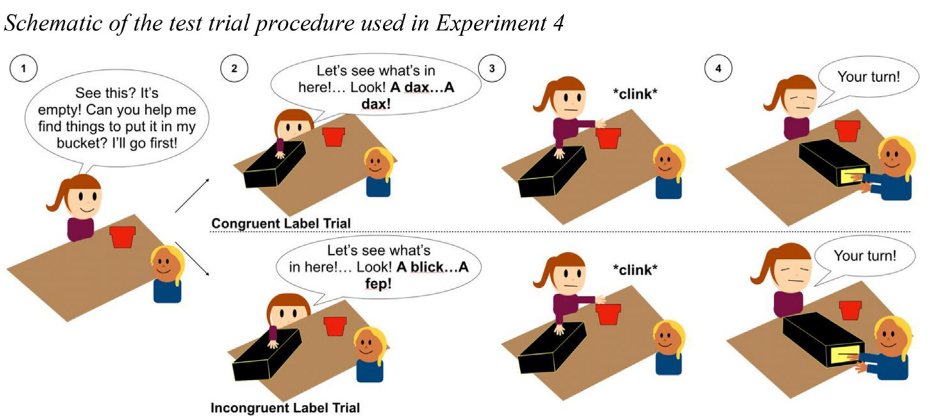

Fig. 5. Schematic of the test trial procedure used in Experiment 4.

the first pair of trials compared to the second. Critically, we observed an interaction between Experiment and Trial Type, $F(1,28) = 4.15$, $p = 0.05$, $\eta^2 = .02$, with children in Experiment 4 showing a greater difference in Incongruent versus Congruent trial searching than children in Experiment 3. There was also a three-way interaction between Experiment, Trial Type, and First Trial Type, $F(1,28) = 11.50$, $p = 0.002$, $\eta^2 = .05$ – children searched the longest during Incongruent trials in Experiment 4 when they received a Congruent trial first. No other interactions were observed, $Fs < 3.01$, $ps > .09$. These results show that 20-month-olds were able to use incongruent novel labels to individuate objects, despite their inability in Experiment 3 to use incongruent emotional responses to solve the same task.

General discussion

In the current experiments we asked whether children can use emotional responses to individuate hidden objects. In Experiments 1 and 3, we found that 26-month old, but not 20-month old children successfully used the contrast between a person's emotional responses (e.g., "Eew! Wow!") to infer the presence of multiple hidden objects. In Experiment 2 we found that this inference required that the emotions be produced by a single observer—when two separate agents expressed the incongruent emotional responses, children did not assume that more than one object was present. Finally, in Experiment 4 we replicated previous findings that infants can use incongruent novel verbal labels to individuate (Xu et al., 2005). This confirms that the failure of the younger 20-month olds in Experiment 3 reflected genuine difficulty in individuating using emotional expressions, rather than more general problems with the task. Hence children have an early understanding of the contrastive nature of emotional expressions, and use this to make inferences about the physical world.[1] This is consistent with an emerging picture in which affective cues appear to support children's reasoning from very early in development (Wu et al., 2021). However, children's understanding of the contrastive nature of emotions appears to undergo change between the first and the second year of life.

This work raises several questions regarding children's ability to reason about emotional responses. One question is whether young children require multi-modal or redundant sources of emotion information to support their inferences. In our experiments, children had access to both visual information (the experimenter's facial expression) and auditory information (the experimenter's vocalizations) to help them differentiate emotional responses. Whether both of these were needed is unclear. Caron et al. (1985) observed simple discrimination of emotions in static faces by 9-months old infants. However, whether inferences about hidden entities, like those explored in the current work, require redundant emotional cues remains open.

Relatedly, our data do not reveal whether children used an early understanding of the words "yay", "yuck", "wow", or "eew" to individuate objects, either in conjunction with or instead of a non-linguistic understanding of emotional expressions (e.g., facial or prosodic cues). One possibility is that, in fact, the development we observed between 18 and 28 months reflects increases in children's understanding of the emotional response words we used; if children are acquiring the meanings of "yuck," "yay," "wow," and "eew" over this time period, they may gradually improve at using these emotion-based words to infer how many objects were present. We note that on this account, even the younger, 20-month olds we tested must have used syntactic cues to differentiate emotional response words from nouns; these younger infants succeeded at using unfamiliar nouns to individuate in Experiment 4 ("A blick! A fep!"), whereas they failed to use emotional response words (e.g., "Yay! Yuck!") to individuate in Experiment 3. An assumption that nouns are mutually exclusive might be in place from early on, whereas no such exclusivity is assumed for emotional responses like "yay." Future work might ask whether emotion words are required to motivate older toddlers' individuation by testing their performance when only facial expressions and non-linguistic sounds are available (i.e., sighs, gasps).

[1] We note that one limitation of this work is the relatively small sample size across experiments (*N=16*). We determined sample size on the basis of previous studies using a similar method (see Barner et al., 2007; Feigenson & Carey, 2005; Stahl & Feigenson, 2018), but we recognize that larger samples are preferable. As such, future work may seek to replicate these findings with larger samples.

Although it is possible that changes in linguistic understanding may have contributed to the age-related differences we observed in children's use of emotions to individuate, non-linguistic developmental changes may also have played a role. In particular, sensitivity to the link between a person's epistemic state and their emotional response appears to increase between 17 and 23 months (see Reschke, Walle, & Dukes, 2017). Wu and colleagues (2018) found that whereas the older children within this age range recognized that an adult actor's emotional response depended on what they had previously seen (or not seen) (see also Scott, 2017), younger children showed no evidence of this. For example, younger toddlers did not find it aberrant when an actor responded with sudden high emotionality to something they had already observed moments earlier. Perhaps relatedly, 14-month old infants fail to use a person's emotional response to predict which of two objects they will reach for (Vaish & Woodward, 2010), although different ways of testing this, or related abilities, have yielded mixed results across ages (Barna & Legerstee, 2005; Siu & Cheung, 2017). Such findings, in concert with our present results, suggest that shortly before their second birthdays, children may be making important strides in their understanding that what people see influences how they will react (as in Wu's study), and that how people react is linked to what they have seen (as in our experiments).

Additional research is also needed on children's ability to make inferences using finer grained distinctions between emotional responses. In our study, children were presented with contrasts between an experimenter reacting with happy excitement ("Yay!") or with disgust ("Yuck!"). We found that children represented these as distinct emotional responses—but it is unclear which responses, exactly. Excitement and disgust are one possibility, but it also could be that children simply noted the contrast between the emotions' positive and negative valences. Children succeed at this coarser distinction by 5 months (Caron et al., 1988). By 18-months, infants can make finer distinctions among different within-valence emotions, such as between anger and disgust (Ruba et al., 2017). Further, Wu et al. (2017) found that 12- to 17-month-old infants can infer the causes of same-valence positive responses. For example, infants recognize that "Mmm!" and "Aww!", though both positive reactions, are elicited by different kinds of objects. Whether young toddlers can reason abstractly using these finer-grained emotion distinctions—for example, recognizing that one individual is unlikely to feel both anger and disgust towards the same object—merits further study.

Lastly, our results highlight the question of when children come to represent the fluid aspect of emotion. Both maturational and experiential factors can cause people's preferences and emotional responses to change over time. Sometimes the vegetable that triggered disgust in childhood comes to elicit delight in the adult. Whether very young children know that emotions and preferences change over time is an area requiring further inquiry. Our findings indicate that 2-year-old children expect emotions to be stable across a short time-span, but children eventually come to recognize that the very same object can prompt someone to feel one way at a particular moment, but a different way later on. This more nuanced view of emotion may emerge later in childhood.

In summary, our findings provide evidence that children as young as 2 years can reason about emotions abstractly. Even in the total absence of information about their antecedents, toddlers inferred that different emotions indicate the presence of numerically distinct objects. Our results do not bear on the important question of where this ability comes from. One prominent view is that the feeling and expression of a handful of basic emotions are innate parts of our evolutionary heritage (Ekman, 1992). Compatible with this is the idea that the propensity to attend to and use others' emotions to make inferences also emerges without learning. Alternatively, some or all aspects of emotional expression might be acquired through experience (e.g., Jack et al., 2012); relatedly, experience also might be needed for children to use emotional signals as useful sources of information about the world. Given that our findings focused on children who were young, but who had already had ample experience with the social world, we remain neutral on this. What our findings do suggest is that sensitivity to the higher order properties of emotions guides children's thinking about the world from early in life.

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Open Data

Data and analyses can be accessed on OSF: https://osf.io/u48gb/.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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