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A happy story: Developmental changes in children's sensitivity to facial expressions of varying intensities

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ABSTRACT

Using 20 levels of intensity, we measured children's thresholds to discriminate the six basic emotional expressions from neutral and their misidentification rates. Combined with the results of a previous study using the same method (*Journal of Experimental Child Psychology*, *102* (2009) 503–521), the results indicate that by 5 years of age, children are adult-like, or nearly adult-like, for happy expressions on all measures. Children's sensitivity to other expressions continues to improve between 5 and 10 years of age (e.g., surprise, disgust, fear) or even after 10 years of age (e.g., anger, sad). The results indicate that there is a slow development of sensitivity to the expression of all basic emotions except happy. This slow development may impact children's social and cognitive development by limiting their sensitivity to subtle expressions of disapproval or disappointment.

Introduction

The ability to accurately recognize other people's facial expressions is important for social interactions but takes surprisingly long to develop. Although infants can categorize some facial expressions (e.g., 5-month-olds [happiness]: Bornstein & Arterberry, 2003; 7-month-olds [surprise]: Caron, Caron, & Myers, 1982; reviewed in Nelson, 1987), it is many years before children reach adults' level of accuracy and speed in recognizing facial expressions (e.g., De Sonneville et al., 2002; Durand, Gallay, Seigneuric, Robichon, & Baudouin, 2007; Kolb, Wilson, & Taylor, 1992; reviewed in Herba & Phillips, 2004). Even though by early adolescence children are adult-like on behavioral measures of recognition, their corresponding brain activity is still different from that of adults until late adolescence (Batty & Taylor, 2006; Monk et al., 2003; Thomas et al., 2001).

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To map this long developmental course, previous studies have used photographs of prototypical expressions from different emotion categories. These prototypical expressions are usually posed by trained actors/actresses using strictly prescribed muscle movements (e.g., Pictures of Facial Affect [Ekman & Friesen, 1976]). The posed expressions usually are high in intensity. With such prototypical expressions, children show a large improvement in accuracy in tasks requiring matching or labeling between 3 and 7 years of age (Camras & Allison, 1985; Durand et al., 2007; Markham & Wang, 1996; Vicari, Reilly, Pasqualetti, Vizzotto, & Caltagirone, 2000), with an improvement in processing speed between 7 and 10 years of age (De Sonneville et al., 2002). There are also different developmental trajectories for different expression categories, with positive expressions being recognized earlier and more accurately than negative expressions (Camras & Allison, 1985; Durand et al., 2007; Kolb et al., 1992; Markham & Adams, 1992; Vicari et al., 2000; Widen & Russell, 2003).

Photographs of intense expressions are a useful tool to study the development of the recognition of facial expressions, but in everyday life we see less intense expressions more frequently than intense facial expressions. Only a few studies have tested children with facial expressions at varying levels of intensity. One method is to select expressions based on adult ratings of their intensity. Gosselin and Pelissier (1996) selected expressions at three intensities based on ratings of the intensity of activation of Facial Action Coding System (FACS) action units (Ekman & Friesen, 1978). They found that 9- and 10-year-olds were as accurate as adults in recognizing happy expressions at all three intensities but were not as good as adults in recognizing disgusted expressions of low intensity. No other age groups or expressions were tested.

A second way to control the intensity of facial expressions is to create blends between a neutral face and an expressive face using a morphing technique (Benson, 1994; Hess, Blairy, & Kleck, 1997) that simulates facial muscle movement in a linear manner. Other than our own work (Gao & Maurer, 2009), three studies have used this technique to study developmental differences. Thomas, De Bellis, Graham, and LaBar (2007) tested with static photos representing 6 levels of fearful or angry expressions. Two other studies tested children with 4–10 levels of intensity of five basic expressions (all except surprise) using a morphing technique in which the children saw animated sequences moving from neutral to successively higher intensities with a fast frame rate (0.05 s/frame [Montirosso, Peverelli, Frigerio, Crespi, & Borgatti, 2010]) or a slow frame rate (1 s/frame [Herba et al., 2008]), and the measure was the frame at which the expression was first recognized. The reported pattern of improvement with age varies with expression and method. For example, Thomas and colleagues (2007) found that both children (7–13 years of age) and adolescents (14–18 years of age) are less sensitive than adults in discriminating static photos of anger and fear from neutral expressions, whereas Montirosso and colleagues (2010) found that sensitivity to animated expressions is already adult-like for anger at 7 years of age and for fear at 10 years of age. Unlike Gosselin and Pelissier (1996), they found no age changes in sensitivity to disgusted expressions. They also reported that sensitivity to happy expressions is already adult-like at 7 years of age, whereas sensitivity to sad expressions is not adult-like until 13 years of age. However, it is not clear whether the improvements with age with their animated technique reflect increased sensitivity to low-intensity expressions or the speed of processing that allows the expression to be recognized after less exposure/fewer frames. Herba and colleagues (2008; see also Herba, Landau, Russell, Ecker, & Phillips, 2006, for results on matching expression across intensity) found improvements in sensitivity for happy and fearful expressions between 4 and 15 years of age for photographs of both familiar and unfamiliar adults with no facilitatory effect of familiarity. However, it was not possible to infer when children's sensitivity reaches adults' levels because there was no adult comparison group.

These previous studies document developmental changes in the accuracy of recognizing facial expressions of varying intensities. However, they fail to distinguish between two types of error. The first type is failure to detect expression at low intensity levels, and the second type, which can occur at any intensity level, is misidentification of one expression as another. Studies using forced-choice procedures without neutral as a choice (Gosselin & Pelissier, 1996; Herba et al., 2008; Montirosso et al., 2010) do not permit identification of the intensity at which children started to see expression in a face (i.e., stopped making the first type of error more frequently than adults). Thomas and colleagues (2007) used a two-alternative forced-choice procedure in which a fearful (or angry) face was shown, followed by a choice between a verbal label of neutral or fearful (angry). Although that procedure measured the first type of error, it did not measure misidentifications between fearful and angry expressions.

In a recent study, we investigated the development of sensitivity to the facial expressions of happiness, sadness, and fear with 20 levels of intensity (Gao & Maurer, 2009). We measured sensitivity with (a) a threshold level of intensity to detect expression in the face (i.e., to see it as non-neutral) and (b) a misidentification rate above the detection threshold. There were different developmental patterns for the three expressions tested. For happiness, even 5-year-olds were as sensitive as adults on both measures. For sadness, by 5 years of age, children had adult-like thresholds to detect expression in sad faces (i.e., to see them as non-neutral), but even at 10 years of age, they were more likely to misjudge sad as fearful. For fear, children's detection thresholds were not adult-like until 10 years of age, and 5-year-olds often confused it with sadness. However, the conclusions of that study are limited by the fact that it included only three facial expressions and, hence, restricted the possible misidentifications among the expressions. In addition, it is also important to investigate the developmental trajectory for other basic facial expressions, namely anger, disgust, and surprise, with a technique that distinguishes between the two types of error.

In the current study, we investigated developmental changes in sensitivity to facial expressions of the six basic emotions at varying intensity levels using the same methodology as in our previous study (Gao & Maurer, 2009). Two groupings of facial expressions were selected based on confusability reported in previous studies of adults (Palermo & Coltheart, 2004): (a) happiness, fear, surprise, and neutral and (b) sadness, disgust, anger, and neutral. Children at 5, 7, and 10 years of age and a comparison group of adults were asked to categorize facial expressions with varying intensities in a game scenario. The intensity levels varied from 0% (neutral) to 100% (peak) for each expression. The results revealed developmental changes in sensitivity to facial expressions of the six basic emotions at different intensities as measured by the threshold to differentiate the expression from neutral and the rate of misidentification among expressions. By comparing the current findings with the findings from our previous study (Gao & Maurer, 2009), we can also examine the effect of context, that is, the effect of the expression groupings on thresholds and misidentification rates for the expressions used in both studies, namely happy, sad, and fearful.

Method

We tested new groups of participants from the same age groups as in our previous study using the same method (Gao & Maurer, 2009).

Participants

The final sample consisted of 24 5.5-year-olds (±3 months), 24 7.5-year-olds (±3 months), 24 10.5-year-olds (±3 months), and 24 adults (18–22 years of age). Half of the participants in each age group were female. Child participants were recruited from names on file of parents who had volunteered their children at birth for participation in later studies. Adult participants were undergraduate students enrolled in an introductory psychology course and received course credit for participation. All of the participants had normal or corrected-to-normal vision. An additional 4 participants (one 5-year-old, one 7-year-old, and two 10-year-olds) were excluded from data analysis because they failed visual screening (criteria: 20/25 for 5- and 7-year-olds, 20/20 for 10-year-olds and adults).

Stimuli

We selected photographs of four models (two male and two female), each posing intense facial expressions of the six basic emotions (happiness, sadness, fear, anger, disgust, and surprise) and neutral from the NimStim Face Stimulus Set (Tottenham et al., 2009, Models 03, 10, 24, and 25). Each photograph had a resolution of 506×650 pixels with RGB color. The facial expressions were generated by professional actors who were instructed to pose specific expressions rather than to make the specific facial muscle movements prescribed in the FACS (Ekman & Friesen, 1978). As a result, some of the posed expressions may include facial action units that are not canonical. Nevertheless, this stimulus set has been validated by high agreement among adults on the posed expressions (Palermo & Coltheart, 2004; Tottenham et al., 2009). For the current study, we chose specific models for which adults have high agreement on the posed expressions (mean = 86.9%, range = 62.5–100) and give high ratings of intensity (mean = 5.5, range = 4.4–6.4, on a 7-point scale) for the expression of all six basic emotions (Palermo & Coltheart, 2004).

For each of the six expressions of each model, we created 20 levels of intensity ranging from 5 to 100% with 5% increments by morphing the emotional face with the neutral face (for details, see Gao & Maurer, 2009). As a result, for each model, there were 121 images (6 expressions × 20 intensities + 1 neutral face) (see Fig. 1 for examples). In total, there were 484 images across the four models. We printed out all of the images in full color using a Canon CP-200 photo printer onto 4 × 6-inch photo paper with lamination. The size of the faces was approximately 7 × 11 cm (width × height).

Design

Each participant finished two testing blocks, with the order of blocks counterbalanced within each sex within each age group. One block consisted of pictures showing happy, surprised, and fearful expressions at all intensity levels from one male model and one female model plus four neutral faces of each model. The other block consisted of pictures showing sad, disgusted, and angry expressions at all intensity levels from one male model and one female model plus four neutral faces of each model. As a result, each block contained 128 pictures ([3 expressions × 20 intensities + 4 neutral faces] × 2 models). Each participant saw the same male model and the same female model in both blocks. Half of the participants of each sex within each age group were assigned to Model 25 (male) and Model 03 (female), and the other half were assigned to Model 24 (male) and Model 10 (female). For the 5-year-olds, pilot work indicated that the procedure was too long, and so (as in our previous study [Gao & Maurer, 2009]) the number of photographs was reduced by using only half of the intensities: 10 levels of intensity with 10% intervals from 10 to 100% for 64 pictures ([3 expressions × 10 intensities + 2 neutral faces] × 2 models) in each block. Therefore, each 5-year-old participant saw 128 pictures, whereas each participant in the other age groups saw 256 pictures.

Procedures

The procedures were approved by the Institutional Research Ethics Board. After the procedures were explained, we obtained written consent from the adult participants or from parents of the child participants, and we obtained verbal assent from the 10-year-olds.

We used the same procedure as in our previous study (for details, see Gao & Maurer, 2009). In each block, the experimenter introduced a game scenario to the participant. In this game, the participant helped people by putting their pictures into appropriate houses according to the expressions/feelings shown on the pictures. Four miniature houses were presented for each block, each with a schematic face (Fig. 2) on its roof showing the three expressions in the block plus neutral. The experimenter introduced the game as follows: "In one of these houses, people are telling a happy [scary or surprising] story [or a story that makes people sad (angry or disgusted) in the other block]. Could you tell me which one it is?" After the participant pointed correctly to the appropriate houses for the three expressions in that block, the experimenter said, "In one house, people are not telling a story and they are not feeling anything. Could you point it out?" After the participant correctly identified the neutral house, the experimenter showed a box with the test photographs inside and said, "Now we have more people here. Your job is to help them to find the right house. They can only go to one house if they have the same feeling as people inside of that house." The experimenter emphasized that there could be different intensities by saying, "One thing you may notice is that sometimes a whole group feels happy, but some feel just a little happy while others feel very happy. In this game, they all go together. Do the same for the surprised and scared people [or for the people who feel sad, angry, or disgusted in the other block]. Don't worry about how surprised or scared they are." The experimenter handed the photographs to the participant one by one. The participant put the photograph into the house that he or she judged as appropriate through a slot in the roof. Because the slots in the roofs of the toy houses

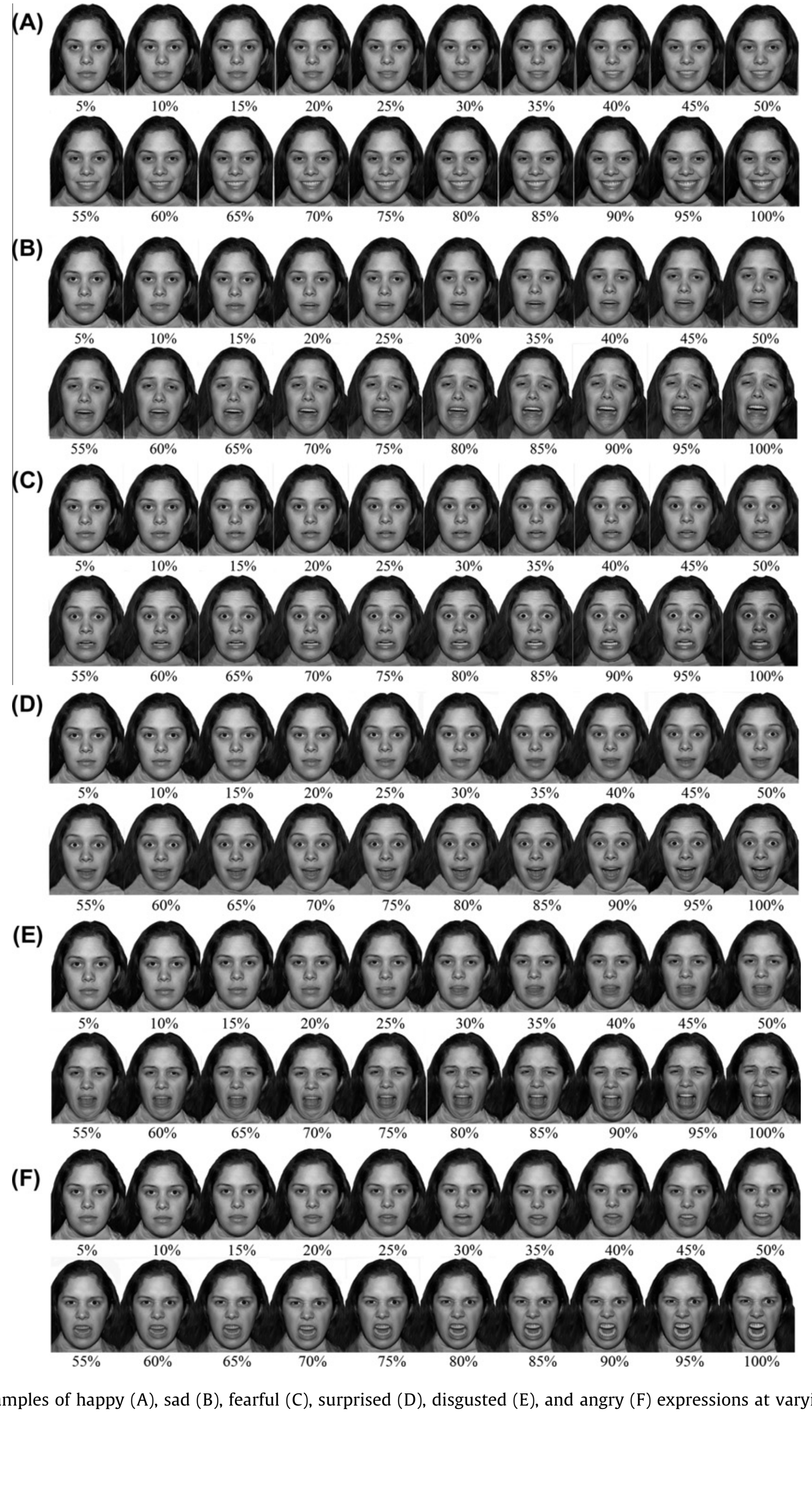

Fig. 1. Examples of happy (A), sad (B), fearful (C), surprised (D), disgusted (E), and angry (F) expressions at varying intensity levels.

Fig. 2. Schematic faces marking the response categories. From left to right: neutral, happy, sad, fearful, surprised, disgusted, and angry.

were very narrow (∼1 cm wide), participants could not see the cards they had already placed in each house. All participants appeared to understand the task and to enjoy the game. Each block took approximately 30 min for children and 25 min for adults to complete. There was a 5-min break between the two testing blocks.

Data analysis

We analyzed the data in the same way as in our previous study (Gao & Maurer, 2009). The data consisted of individual accuracy scores at each intensity level for each expression averaged across the two models seen by that participant. The means for each age group and expression are shown in Fig. 3. However, there were two types of error: (a) at low intensities, misidentifying an expressive face as neutral and (b) at high intensities, misidentifying one expression as another (e.g., classifying a sad expression as fearful). Therefore, we did not use accuracy as the main measure of children's sensitivity to facial expressions. Instead, we quantified these two types of error by (a) calculating the threshold to discriminate each expression as different from neutral and (b) calculating the misidentification rates above the threshold.

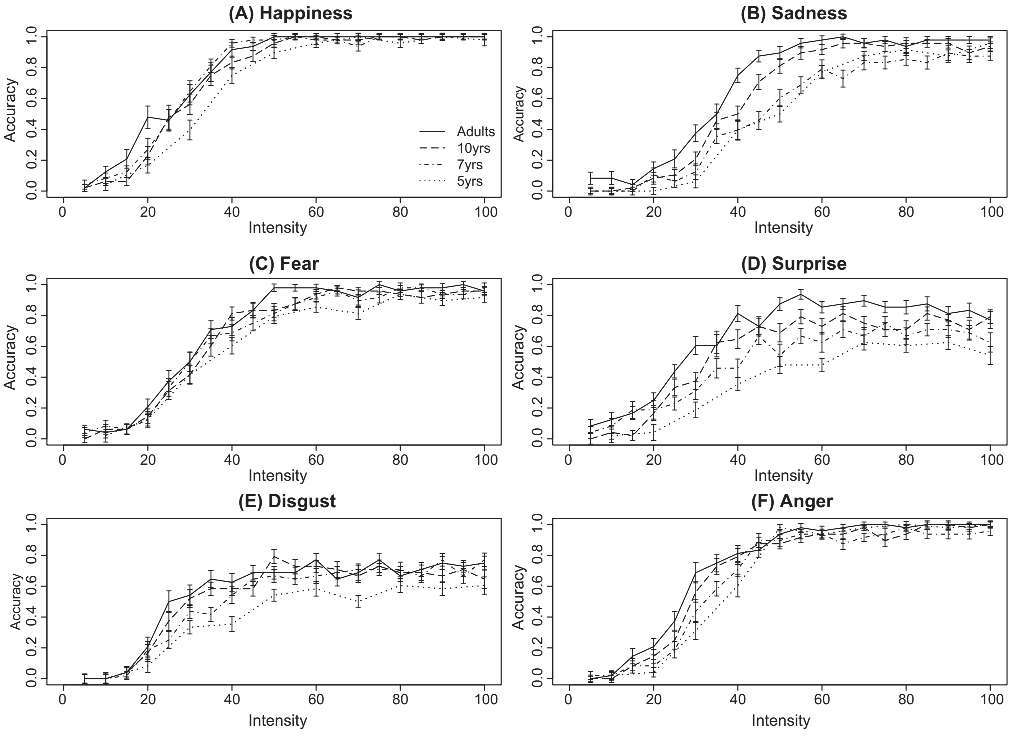

Fig. 3. Mean accuracy (±1 standard error) for each expression at each age as a function of intensity: (A) happiness, (B) sadness, (C) fear, (D) surprise, (E) disgust, (F) anger.

Thresholds

To calculate individual thresholds to discriminate each expression from neutral, we categorized each participant's responses as neutral or non-neutral, with non-neutral responses including both correct identifications (e.g., 50% happiness identified as happy) and misidentifications (e.g., 50% happy identified as surprise). Fig. 4 shows the mean proportion of non-neutral response for each expression and age group. We fitted a cumulative Gaussian function to the responses of each participant for each expression in each age group by using the following formula:

$$P_{\text{discrimination}} = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{x} \exp\left(-\frac{(u-\mu)^2}{2\sigma^2}\right) du,$$

where x is intensity and $P_{\text{discrimination}}$ is the probability of discrimination. The two parameters, μ and σ, are the mean and standard deviation, respectively, of the normal distribution $X \sim N(\mu, \sigma^2)$. We estimated μ by using a maximum likelihood procedure. In this procedure, for each participant and expression, we first calculated the likelihood values of the 400 possible combinations of the 20 values of μ (5–100% with a step size of 5%) and the 20 values of σ (5–100% with a step size of 5%) given the cumulative Gaussian function. We then marginalized the estimation of σ by summing the likelihood values across all of the values of σ for each value of μ. After marginalization, we used the μ value corresponding to the highest likelihood value as the estimation of threshold. This value corresponds to $P = .50$, that is, the intensity level at which the expressive face will be recognized as neutral 50% of the time and it will be recognized as expressive 50% of the time. This procedure gave us the best estimate of μ while minimizing the influence of σ on the estimate. We calculated each participant's threshold for each expression by averaging across the independently derived threshold estimates for the two models.

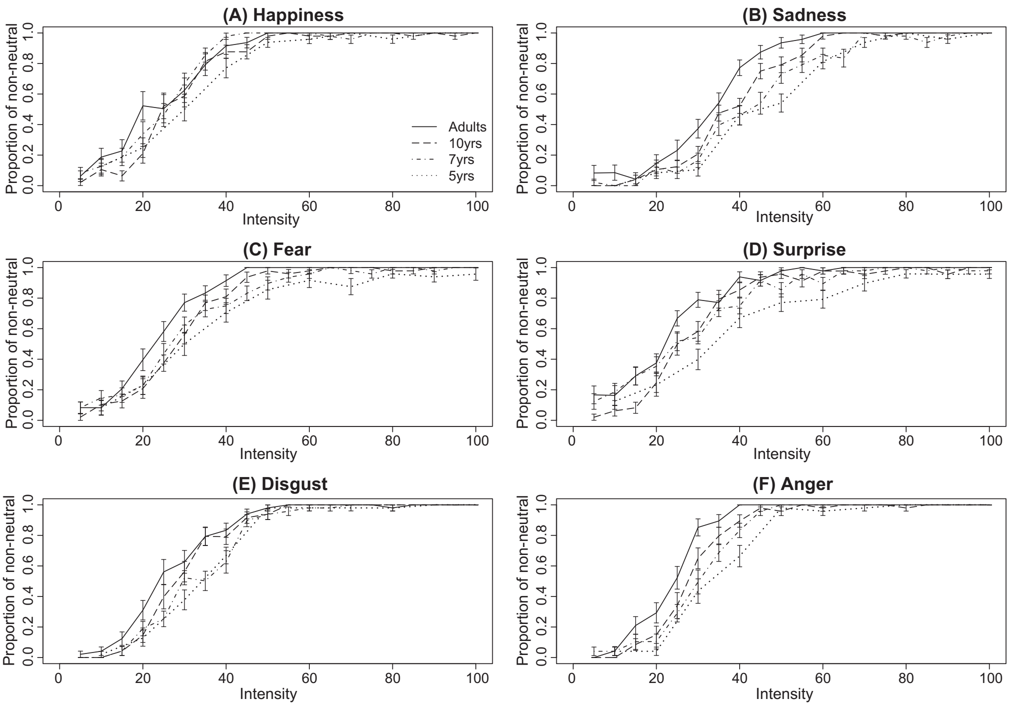

Fig. 4. Mean proportion of non-neutral response (±1 standard error) for each expression at each age as a function of intensity: (A) happiness, (B) sadness, (C) fear, (D) surprise, (E) disgust, (F) anger.

Misidentification rates

We categorized non-neutral responses into correct responses and misidentifications. We calculated misidentification rates for each participant by dividing the frequency of misidentification by the total number of non-neutral responses the participant made across all intensity levels. The misidentification rates for each participant were calculated separately for the two models and then averaged. Table 1 indicates the mean number of faces that were chosen as non-neutral (the denominator in the calculation of the misidentification rates) at each age for each expression.

Analyses

For all of the dependent measures, we applied a nonrecursive outlier elimination procedure with a cutoff of 2.4 standard deviations based on the distribution for each facial expression tested at each age (Van Selst & Jolicoeur, 1994). We removed 1.7, 2.6, and 3.0% of the scores as outliers for thresholds (three cases for 5-year-olds, three cases for 7-year-olds, one case for 10-year-olds, and three cases for adults), misidentification rates (three cases for 5-year-olds, four cases for 7-year-olds, four cases for 10-year-olds, and four cases for adults), and accuracy scores at peak intensity (four cases for 5-year-olds, two cases for 7-year-olds, seven cases for 10-year-olds, and four cases for adults), respectively.

Preliminary analysis showed no effect of assignment to Models 03 and 25 or Models 10 and 24 on the results for either threshold or misidentification; therefore, we did not include model grouping as a factor in the main analyses. For both thresholds and misidentification rates, we conducted one-way analyses of variance (ANOVAs) with age as a between-participant variable separately for each expression. We also ran the same ANOVA on accuracy for the peak intensity expressions (100%) to allow direct comparison of our results with those of previous studies that used only intense expressions. Significant main effects of age were analyzed by Dunnett's tests comparing each group of children with adults (one-tailed, testing the null hypothesis that children's performance is as good as that of adults).

The main analyses were conducted separately for each expression because we could not be sure that the 100% intensity examples were equivalently near the maximum possible expression for that emotion and, hence, that the 5% increments were scaled equally across expressions. This is an issue in any study comparing facial expressions. To minimize the problem, we chose the 100% intensity examples to be similar based on adult accuracy and intensity ratings in published norms (see "Stimuli" section). Analyses comparing the physical difference of each expression from neutral also suggest that the scaling was similar across expressions (see "Discussion"). Nevertheless, the ratings and physical differences were not identical for the six expressions; hence, we took the more conservative approach of separately analyzing the effect of age on each expression for each of the three measures. This approach is also justified by an Age $\times$ Expression interaction for all three measures in a mixed-model ANOVA that includes age and sex as between-participant variables and expression as a repeated measure: thresholds, $F(10.4, 273.7)$, Greenhouse–Geisser corrected = 2.9, $p < .01$, partial $\eta^2 = .10$; misidentification, $F(7.3, 182.1)$, Greenhouse–Geisser corrected = 1.2, $p < .05$, partial $\eta^2 = .10$; accuracy at peak intensity, $F(15, 365) = 3.6$, $p < .01$, partial $\eta^2 = .13$. Those analyses also indicated that female participants had slightly lower thresholds ($\text{mean}_{\text{female}} = 26.1\%$, $\text{mean}_{\text{male}} = 29.4\%$), $F(1, 79) = 8.6$, $p < .01$,

Table 1
Mean number of faces identified as expressive for each expression averaged across models.

	Happiness	Sadness	Fear	Surprise	Disgust	Anger
5-year-olds	7.5 (75)	5.9 (59)	7.0 (70)	6.8 (68)	7.1 (71)	7.1 (71)
7-year-olds	15.6 (78)	11.9 (60)	14.7 (74)	15.0 (75)	13.9 (70)	14.6 (73)
10-year-olds	15.0 (75)	13.1 (66)	14.9 (75)	14.9 (75)	14.6 (73)	14.9 (75)
Adults	15.8 (79)	14.0 (70)	15.9 (80)	16.0 (80)	15.2 (76)	15.8 (79)

Note. Percentages are in parentheses. For each expression, 5-year-olds saw 10 faces of each model, whereas other age groups saw 20 faces of each model. The numbers shown are the denominators used in the calculation of rates of misidentification.

partial η^2 = .10, and misidentification rates ($mean_{female}$ = 0.12, $mean_{male}$ = 0.15), $F(1, 75) = 4.9$, $p < .05$, partial η^2 = .06, than male participants. Sex did not interact with age or expression and did not affect accuracy at peak intensity (all $ps > .10$).

Results

Happy expressions

In all four age groups, accuracy started to increase with intensity from a very low level (~10%) and reached ceiling at approximately 60% intensity (Fig. 3A). All age groups had perfect accuracy (100%) at the peak intensity. The mean threshold was approximately 25% for all age groups (Table 2), and there was no significant effect of age, $F(3, 91) = 1.0$. For misidentification rates, in contrast, there was a significant main effect of age, $F(3, 88) = 4.6$, $p < .01$, partial η^2 = .14. Although the misidentification rates were low (less than 5% for all age groups) (see Table 3), 5-year-olds had significantly higher misidentification rates than adults ($p < .05$, Cohen's $d = 0.9$). The 5-year-olds' misidentifications were most likely to occur in the mid-intensity range of approximately 20–50% (Fig. 3A) and usually involved misinterpreting happy faces as surprised faces (Table 3). Thus, by 5 years of age, children are nearly as sensitive as adults to expressions of happiness, with no significant difference on any measure by 7 years of age.

Sad expressions

For sad expressions, accuracy increased between 20 and 70% (Fig. 3B), but the four age groups diverged in this range, with both 5- and 7-year-olds deviating from adults on some measures. Even at peak intensity (100%), there was a significant effect of age on accuracy, $F(3, 86) = 7.0$, $p < .01$, η^2 = .20, with 7-year-olds having significantly lower accuracy (88%) than adults (100%) ($p < .05$, Cohen's $d = 1.1$), whereas 5- and 10-year-olds were as accurate as adults. The differences in the mid-intensity range were captured by a significant effect of age on threshold, $F(3, 91) = 9.8$, $p < .01$, η^2 = .25, with both 5- and 7-year-olds having higher thresholds than adults ($ps < .05$, Cohen's ds = 1.3 and 1.2, respectively), and a significant effect of age on misidentification rate, $F(3, 88) = 4.0$, $p < .05$, η^2 = .12, with 7-year-olds having a higher misidentification rate than adults ($p < .05$, Cohen's $d = 1.0$). The major type of misidentification was to classify sad faces as disgusted (Table 3). Thus, both 5- and 7-year-olds are more likely than older groups to classify a mid-range sad face as neutral; in addition, 7-year-olds are more likely to misidentify it as conveying a different emotion, usually disgust, even at peak intensity. It is only between 7 and 10 years of age that children become as sensitive as adults on all three measures.

Fearful expressions

For fearful expressions, the curves for the four age groups are quite close to each other, with accuracy increasing with intensity between 5 and 55% (Fig. 3C). All age groups performed well at peak intensity with no main effect of age, $F(3, 86) = 2.0$, $p = .12$. The thresholds ranged from 20.7% (adults) to 29.6% (5-year-olds) (Table 2). There was a significant effect of age on threshold, $F(3, 89) = 3.1$,

Table 2
Mean thresholds.

	Current study						Gao and Maurer (2009)		
	Happiness	Sadness	Fear	Surprise	Disgust	Anger	Happiness	Sadness	Fear
5-year-olds	26.0 (10.4)	42.7 (11.0)	29.6 (13.4)	35.2 (15.7)	27.8 (6.7)	28.0 (6.3)	23.8 (9.6)	31.0 (10.2)	30.0 (12.4)
7-year-olds	22.1 (7.9)	41.9 (10.1)	26.1 (8.3)	24.0 (8.4)	31.1 (7.4)	28.0 (5.6)	23.3 (7.8)	32.5 (9.4)	30.8 (10.2)
10-year-olds	25.1 (8.7)	35.0 (5.7)	26.1 (7.2)	24.7 (6.1)	27.2 (7.3)	25.5 (7.0)	17.7 (6.9)	30.3 (9.0)	22.3 (8.4)
Adults	20.8 (10.5)	31.1 (6.5)	20.7 (5.7)	20.2 (5.3)	23.9 (7.3)	20.9 (5.0)	20.8 (9.5)	27.5 (7.9)	19.7 (7.2)

Note. Standard deviations are in parentheses.

Table 3
Mean misidentification rates.

	Current study								
	Happiness			Surprise			Fear		
Misidentified as:	Surprise	Fear	Total	Fear	Happiness	Total	Surprise	Happiness	Total
5-year-olds	3.1	1.6	4.7	24.1	17.0	41.1	6.6	1.8	8.4
7-year-olds	0.6	0.9	1.5	20.4	12.3	32.7	6.1	0.9	7.0
10-year-olds	0.3	0.6	0.9	15.8	8.9	24.7	7.0	0.4	7.4
Adults	0.4	0.3	0.7	12.8	4.8	17.6	10.1	0.5	10.6
	Sadness			Disgust			Anger		
Misidentified as:	Disgust	Anger	Total	Sadness	Anger	Total	Disgust	Sadness	Total
5-year-olds	4.6	1.9	6.5	37.2	4.1	41.3	1.8	0.7	2.5
7-year-olds	10.5	0.5	11.0	26.0	0.8	26.8	5.5	0.5	6.0
10-year-olds	4.3	0.3	4.6	26.6	1.0	27.6	5.1	0.9	6.0
Adults	2.1	0	2.1	26.4	0.3	26.7	5.6	0.7	6.3
	Gao and Maurer (2009)								
	Happiness			Sadness			Fear		
Misidentified as:	Sadness	Fear	Total	Happiness	Fear	Total	Happiness	Sadness	Total
5-year-olds	0.3	2.4	2.7	3.0	12.4	15.4	2.6	22.9	25.5
7-year-olds	0.5	0.4	0.9	3.4	10.0	13.4	1.2	7.0	8.2
10-year-olds	0.6	0.5	1.1	4.0	10.6	14.6	2.8	5.9	8.7
Adults	1.3	0.8	2.1	0.3	5.0	5.3	0.9	4.1	5.0

Note. Values are percentages.

$p < .05$, $\eta^2 = .10$. The 5-year-olds showed a significantly higher threshold to detect expression in fearful faces than the adults ($p < .05$, Cohen's $d = 0.9$), but there was no difference between adults and the two older child groups (all $ps > .10$). All four age groups made approximately 10% misidentifications, mainly from a confusion of fear with surprise (Table 3); there was no effect of age on misidentification rates, $F(3, 89) < 1$. Thus, school-aged children are as sensitive to fearful expressions as adults except for a higher threshold at 5 years of age.

Surprised expressions

For surprised expressions, accuracy increased slowly with intensity and approached an asymptote only beginning at approximately 60% (Fig. 3D). At peak intensity, accuracy ranged from only 54% (5-year-olds) to 77% (adults). There was a significant effect of age on accuracy at peak intensity, $F(3, 90) = 3.7$, $p < .05$, $\eta^2 = .11$, and threshold, $F(3, 89) = 10.1$, $p < .01$, $\eta^2 = .25$, with 5-year-olds having lower accuracy than adults at peak intensity ($p < .05$, Cohen's $d = 0.6$) and higher thresholds ($p < .05$, Cohen's $d = 1.5$), but there was no difference between adults and the two older child groups. All four age groups made a substantial number of misidentifications, which ranged from 17.6% (adults) to 41.1% (5-year-olds), mainly from the confusion of surprise with fear (Table 3). The effect of age on misidentification rates was significant, $F(3, 92) = 4.1$, $p < .01$, $\eta^2 = .12$, with 5- and 7-year-olds making more misidentifications than adults ($ps < .05$, Cohen's $ds = 1.0$ and 0.6, respectively) but no significant difference between 10-year-olds and adults ($p = .32$). Thus, 5-year-olds are less sensitive than adults to surprised expressions even at peak intensity; sensitivity to the expressiveness in surprised faces improves to adult levels by 7 years of age, but children still make significantly more misidentifications; it is only between 7 and 10 years of age that sensitivity becomes adult-like by all three measures.

Disgusted expressions

For disgusted expressions, for all four age groups, accuracy increased sharply in the low intensity range (~10–30%), followed by slower increases over a broad intensity range (35–100%) (Fig. 3E). At peak intensity, accuracy ranged from 60% (5-year-olds) to 70% (adults) and there was no significant effect of age, $F(3, 91) = 2.0$, $p = .12$. There was a significant main effect of age on thresholds, $F(3, 91) = 4.1$, $p < .01$, $\eta^2 = .12$, with 7-year-olds having a higher threshold than adults ($p < .05$, Cohen's $d = 1.0$). There was also a significant effect of age on misidentification rate, $F(3, 92) = 2.8$, $p < .05$, $\eta^2 = .08$, with 5-year-olds making significantly more misidentifications than adults ($p < .05$, Cohen's $d = 0.7$). The misidentification rates ranged from 26.7% (adults) to 41.3% (5-year-olds). All age groups tended to misidentify disgusted faces as sad (Table 3). Thus, 5- and 7-year-olds differ from adults in more often misidentifying disgusted faces as sad (5-year-olds) or neutral (7-year-olds); it is only between 7 and 10 years of age that children become as sensitive as adults on all measures.

Angry expressions

For angry expressions, accuracy increased sharply from 20 to 50% for all four age groups and reached ceiling at approximately 55% (Fig. 3F). All age groups had perfect accuracy (100%) at peak intensity. There was a significant effect of age on thresholds, $F(3, 90) = 7.3$, $p < .01$, $\eta^2 = .20$, with all three groups of children having higher thresholds than adults (ps < .05, Cohen's ds = 1.2, 1.2, and 0.8 for 5-, 7-, and 10-year-olds, respectively). The misidentification rates for all age groups were less than 7% (Table 3), with no difference among age groups, $F(3, 88) = 1.4$, $p = .26$. Thus, throughout the age period between 5 and 10 years, children are more likely than adults to miss the expressiveness in an angry face at lower intensities and to mistake it as neutral.

Effect of number of levels of intensity

We tested 5-year-olds with only 10 levels of intensity, whereas we tested the other age groups with 20 levels of intensity. The thresholds and misidentification rates estimated with more levels of intensity may be more accurate than those for 5-year-olds estimated with fewer levels of intensity. (Peak intensity was the same for all ages and, hence, was not affected by this difference.) We investigated how the difference affected the developmental patterns by recalculating the thresholds and misidentification rates of adults based on responses for the 10 levels of intensity used with 5-year-olds. The results for the misidentification rates were identical to those reported above. The results for thresholds were similar to what is reported above except that the thresholds of adults for happy and disgusted expressions were significantly lower (i.e., better) than those of 5-year-olds in the new calculation but not the original one. We have not highlighted these differences because adults' thresholds based on more levels of intensity are likely to be more accurate. In any event, we can rule out the possibility that the immaturities we reported above for 5-year-olds are from overestimating their thresholds and misidentification rates based on fewer levels of intensity than used with the other age groups.

Effect of expression grouping

The choices of answers in the forced-choice procedure may affect the patterns of developmental changes found in this study. To investigate the effect of expression grouping, we compared the current findings with those from our previous study (Gao & Maurer, 2009), in which we tested children's sensitivity to happy and fearful expressions grouped with sad instead of surprise as in the current study. We also compared sensitivity to sad expressions in our previous study (when grouped with happy and fearful) with that in the current study (when grouped with anger and disgust). Specifically, for each of the three expressions that was common to the two studies, we used an ANOVA for each measure (accuracy at peak intensity, threshold, and misidentification rate) with two between-participant factors (age and study).

For happy expressions, there was no significant effect of study or interaction between study and age on any measure (all ps > .09). Therefore, our sensitivity measures for happy expressions were not affected by the specific grouping of expressions. For fearful expressions, there were significant interactions between study and age on both misidentification rates, $F(3, 181) = 6.9$, $p < .01$, partial $\eta^2 = .10$, and accuracy at peak intensity, $F(3, 178) = 5.6$, $p < .01$, partial $\eta^2 = .08$. Both interactions were caused by the fact that in our previous study (Study 1) 5-year-olds misidentified fearful expressions as sad at a higher rate than adults at all intensities (Table 3). For fearful expressions, there was no main effect of study on any measure or an interaction between study and age on thresholds (all *p*s > .10).

For sad expressions, there were significant main effects of study on both threshold, $F(1, 3) = 14.7$, $p < .05$, partial $\eta^2 = .83$, and misidentification rates, $F(1, 3) = 10.7$, $p < .05$, partial $\eta^2 = .78$. Participants in Study 1 generally had higher misidentification rates than participants in the current study (Study 2) as a result of more misidentifications of less intense sad expressions as fearful in Study 1 (>10% in the three groups of children and 5% in adults) (Table 3). Participants in Study 2 generally had higher (worse) thresholds for sad expressions than participants in Study 1 (Table 2). The elevated thresholds in Study 2 may be related to the fact that only negative expressions and neutral were included, whereas in Study 1 sad expressions were tested with both positive and negative expressions. However, the exact reason for the elevation in threshold for sad expressions in Study 2 is not clear. For sad expressions, there was no main effect of study on accuracy for peak intensity expressions or an interaction between study and age on any measure (all *p*s > .05).

These analyses indicate that the available choices in the forced-choice procedure affected the patterns of developmental changes in children's sensitivity to fearful and sad expressions mainly because children, but not adults, confused sad and fearful expressions in Study 1. Grouping also affected the threshold to differentiate sad expressions from neutral. However, the reason for the latter effect is not clear.

Discussion

Using facial expressions with varying intensities, we investigated children's sensitivity to facial expressions of the six basic emotions by measuring their thresholds to discriminate each expression from neutral and the rates of misidentification. Like previous studies (e.g., Camras & Allison, 1985; Durand et al., 2007; Kolb et al., 1992; Markham & Adams, 1992; Vicari et al., 2000; Widen & Russell, 2003), we found different developmental trajectories for sensitivity to different facial expressions. The current findings extend previous findings by using less intense facial expressions, of the type seen more frequently in everyday life, and by differentiating children's errors into those involving a failure to see that the face is expressing an emotion and those involving errors in identifying the emotion expressed. Below we compare our findings for each expression with those found in the literature, consider methodological limitations that might have affected the results, and then offer hypotheses about possible causes of the different developmental trajectories for different emotional expressions.

We also found a small but reliable effect of sex that did not interact with expression or age. Female participants had lower (better) thresholds than male participants (Cohen's $d = 0.56$) and lower rates of misidentification (Cohen's $d = 0.37$). Such a female advantage is consistent with the results from a previous meta-analysis on sex difference in sensitivity to facial expression (McClure, 2000). However, the effect found here is small, and there are also studies that did not find a sex difference with either intense expressions (e.g., De Sonneville et al., 2002; Vicari et al., 2000) or expressions of varying intensities (e.g., Gao & Maurer, 2009; Herba et al., 2006, 2008).

Happiness

However measured, sensitivity to happy expressions develops more quickly than sensitivity to any other expression. For example, infants just 1–4 days old look longer at a happy face than at a fearful face with which it is paired, perhaps as a result of experience immediately after birth (Farroni, Menon, Rigato, & Johnson, 2007). Our results are consistent with previous studies indicating that young children's accuracy in recognizing happy expressions is better than their accuracy in recognizing other expressions (Camras & Allison, 1985; Durand et al., 2007; Kolb et al., 1992; Markham & Adams, 1992; Vicari et al., 2000; Widen & Russell, 2003) and that by 5 years of age children are as sensitive as adults in recognizing intense happy expressions (Durand et al., 2007). Five studies have used less intense expressions, and the results differ between those using dynamically varying intensities (Herba et al., 2008; Montirosso et al., 2010) and those using static photos of different intensities

(Gao & Maurer, 2009; Gosselin & Pelissier, 1996; this study). Herba and colleagues (2008) reported an improvement between 4 and 15 years of age in the minimum intensity needed to recognize a happy expression increasing dynamically in intensity at 1 s/frame. With a shorter interval between frames (0.05 s/frame), Montirosso and colleagues (2010) also found improvement with age in accuracy to recognize happy expressions increasing dynamically in intensity, but the increase was significant only between the 4- to 6-year-old group and the 7- to 9-year-old group, with no further change until adulthood. The improvement on dynamically displayed expression may reflect changes in children's speed in processing facial expressions, which is known to increase between 7 (the youngest age tested) and 10 years of age, with a further increase by adulthood (De Sonneville et al., 2002). Using static images of facial expressions of varying intensities, we found that children's threshold for discriminating a subtle happy expression from neutral is adult-like by 5 years of age regardless of whether the expression is grouped with fear and sadness (Gao & Maurer, 2009) or surprise and fear (this study). Gosselin and Pelissier (1996) also found adult-like accuracy at 9 or 10 years (the youngest age tested) when three intensities of happy were paired with the other five basic emotions but not neutral. Nevertheless, in the current study, 5-year-olds made more misidentifications than adults for the intermediate intensities when happy expressions were grouped with another expression that can be construed as positive (e.g., surprise), although the misidentification rate was still low (<5%). In addition, in our previous study (Gao & Maurer, 2009), we found that both 5- and 7-year-olds are not as good as adults at detecting small differences in the intensity of mid-intensity happy expressions. Together, the evidence suggests that by 5 years of age, children are as sensitive as adults to subtle facial expressions of happiness (Gao & Maurer, 2009; this study), although it takes them longer than adults to perceive the expressive cues (De Sonneville et al., 2002; Herba et al., 2008; Montirosso et al., 2010); they occasionally mistake subtle facial expressions of happiness for surprise (this study); and they are not as good as adults at noticing small increases and decreases in the intensity of the expression (Gao & Maurer, 2009). The adult-like thresholds and low misidentification rate should allow children to pick up subtle positive feedback from their peers and from adults, thereby helping them to react appropriately in social interactions. With age, they will become more sensitive to small differences in that feedback and pick it up more quickly.

Sadness

By 12 month of age, infants are able to use mothers' facial expressions to disambiguate situations and respond differently to sad expressions than they do to happy, fearful, or angry expressions (Sorce, Emde, Campos, & Klinnert, 1985). When asked to cross the deep side of a visual cliff, they are likely to do so if the mother poses happy (14 of 19 infants) or interest (11 of 15 infants) expressions, but not if she poses fearful (0 of 17) or angry (2 of 18) expressions. Unlike happy, interest, fearful, or angry expressions, sad expressions do not signal whether the situation should elicit avoidance or approach. Consistent with this analysis, 6 of 18 infants crossed to the deep side when the mother posed sadness, a value not different from baseline. Therefore, by 12 month of age, infants not only are able to discriminate sad expressions from other expressions but also may understand the meaning of sad expressions.

Previous studies of children using intense sad expressions have reported early development of the ability to recognize them as accurately as adults (Camras & Allison, 1985; De Sonneville et al., 2002; Durand et al., 2007), consistent with our findings for high-intensity expressions (> $\sim$88%); the exception is Kolb and colleagues (1992), who found lower accuracy in all age groups between 6–7 and 12–13 years of age than in adults. Studies using less intense dynamic expressions also reported slow development, with changes in the intensity at which the expression is recognized up to 13–15 years of age (Herba et al., 2008; Montirosso et al., 2010). These findings may reflect increases in the speed of processing subtle sad expressions. Our results for static sad expressions indicate that, in addition, there are improvements in threshold and reductions in misidentifications, although the exact pattern depends on the grouping of expressions. When sad expressions were grouped with happy and fearful expressions, there were no differences in threshold, but children as old as 10 years (the oldest tested) misidentified sad faces as fearful more than twice as often as adults (10.6 vs. 5.0%) (Gao & Maurer, 2009). When sad expressions were grouped with only negative expressions (e.g., disgust and anger) in the current study, 10-year-olds were adult-like, but 7-year-olds deviated on all three measures; they made more errors at peak intensity, needed more intensity than adults to discriminate sad faces from neutral (i.e., had higher thresholds), and more often misidentified sad faces as disgusted. Combined with previous results, the data suggest that young children are slower than adults at identifying subtle expressions of sadness and are more likely to misidentify them as neutral, disgusted, or fearful. Some of these differences persist until early adolescence. Thus, children may miss or misread subtle signals of sadness and, consequently, may fail to show empathy to people with subtle sad expressions.

Fear

Although newborns show no evidence of discriminating intense fearful expressions from neutral (Farroni et al., 2007), by 7 months of age infants categorize intense fearful expressions across different individual faces, look longer at such fearful faces than at happy faces, and disengage attention more slowly from intense fearful faces than from neutral or happy faces so as to look at a peripheral target (Nelson & Dolgin, 1985; Peltola, Leppänen, Mäki, & Hietanen, 2009; Peltola, Leppänen, Palokangas, & Hietanen, 2008). As summarized above, by 12 months (the youngest age tested), they also appear to understand the meaning of fearful expressions and respond appropriately to them by avoiding the deep side of the visual cliff (Sorce et al., 1985). This early onset of processing of fearful faces is consistent with the important evolutionary role of fear in signaling potential environmental threat.

Nevertheless, adult-like sensitivity to fearful expressions develops relatively late whether children are tested with intense exemplars (De Sonneville et al., 2002; Durand et al., 2007; Kolb et al., 1992) or with expressions of varying intensities (Gao & Maurer, 2009; Herba et al., 2008; Montirosso et al., 2010; Thomas et al., 2007; this study). Thus, previous studies using varying intensities reported that children of approximately 7–9 years of age have higher thresholds than adults (Gao & Maurer, 2009; Thomas et al., 2007), with continuing changes up to 15 years of age in one study using dynamically changing intensities (Herba et al., 2008; but see Montirosso et al., 2010). The current findings indicate that the details of the developmental pattern vary with the grouping of expressions with which fear can be confused. When fear is grouped with sadness, 5-year-olds misidentify it as sad more than five times as often as adults (22.9 vs. 4.1%) and do so even at peak intensity (Gao & Maurer, 2009). The confusion between fear and sadness is greatly reduced by 7 years of age (Gagnon, Gosselin, Hudon-ven der Buhs, Larocque, & Milliard, 2010; Gao & Maurer, 2009). When fear is grouped with happy and surprise, as in the current study, all age groups confuse it with surprise at fairly high rates ($\sim$10%), but the error is no more likely in children than in adults. As in our previous study, however, 5-year-olds needed more intensity than adults to detect expression in fearful faces; that is, their thresholds were approximately 50% higher (29.6 vs. 20.7% in this study; 30.0 vs. 19.7% in our previous study). By 10 years of age, children are adult-like on all measures of sensitivity to fear in static faces of varying intensities whether it is grouped with sadness or with surprise. The slow development of sensitivity to fearful expressions may be a result of low exposure in everyday life. Consequently, young children (5-year-olds) may fail to identify signals of potential danger in the environment evident in other people's facial expressions and may misconstrue even intense fearful expressions as sad.

Anger

Anger is another facial expression that has high evolutionary signal value because it provides cues to retreat or prepare to defend oneself. As noted above, by 12 months (the youngest age tested), infants appear to understand this signal value because it keeps them from crossing into the deep side of the visual cliff (Sorce et al., 1985). Previous studies using either intense expressions or expressions varying in intensity agree that the developmental trajectory after infancy is as long as that for fearful expressions (Camras & Allison, 1985; Gagnon et al., 2010; Kolb et al., 1992; Markham & Adams, 1992) or even slightly longer (Durand et al., 2007; Montirosso et al., 2010; Thomas et al., 2007). The current study indicates that the long developmental trajectory arises mainly from higher thresholds as late as 10 years (the oldest age tested), that is, from children's mistaking a low- or mid-intensity angry expression as neutral. Once they see the face as expressive, children as young as 5 years are no more likely than adults to confuse it with disgust or sadness. It is unclear whether there is also an increase in the speed of processing angry expressions during childhood (cf. the improvement in processing speed and accuracy in De Sonneville et al., 2002, and Montirosso et al., 2010, with the flat functions in Herba et al., 2008). The slow development of sensitivity to angry expressions may reflect children's rare exposure to angry expressions in everyday life. In contrast, at 9 years of age, physically abused children, who are likely to have more than the usual amount of exposure to anger, have a lower threshold to detect anger in a face but perform like typically developing children in detecting happy and fearful expressions (Pollak & Sinha, 2002). The failure to detect subtle angry expressions in typically developing children between 5 and 10 years of age may keep them from appropriately interpreting the reaction of others to angry-provoking actions and may limit what they can learn from social feedback about inappropriate behaviors.

Surprise

By 6 or 7 months of age, infants categorize surprised expressions across different individual faces and discriminate surprised from happy expressions (Caron et al., 1982) and angry expressions (Serrano, Iglesias, & Loeches, 1992). The later development of sensitivity to surprise is not well charted because many previous studies of children did not include surprise among the expressions tested (e.g., De Sonneville et al., 2002; Herba et al., 2008; Montirosso et al., 2010) or did not include an adult comparison group (e.g., Gosselin & Larocque, 2000; Markham & Adams, 1992; Vicari et al., 2000). In the one previous study using intense expressions and an adult comparison group, children were less accurate than adults as late as 12 or 13 years of age (Kolb et al., 1992). One reason for children's poor accuracy may be the fact that surprised expressions share muscle action units with fearful expressions (Ekman & Friesen, 1978; Gosselin & Simard, 1999), a commonality likely contributing to high rates of confusion between fear and surprise even in adults. Interestingly, in the current study, 5- and 7-year-olds were twice as likely as adults to misidentify surprised expressions as fearful (error rates of 20–24 vs. 12.8%) but were no more likely to misidentify fearful expressions as surprised at any age (error rates of 6–10%). The 5-year-olds also confused surprised expressions with happy expressions three times more often than adults (17 vs. 4.8%) and had higher thresholds to see them as non-neutral. The pattern of misidentification in 5-year-olds may be a result of the ambiguity in the valence of surprised expressions, which can be either positive (e.g., a surprise gift) or negative (e.g., the onset of an unexpected unpleasant event). In everyday life, contextual information may help children to decode the ambiguity in the valence of surprised expressions, although children's ability to use such contextual information remains largely unexplored. Alternatively, in the faces of the two female models depicting surprise, there was activation of the lip corner puller, which is typically seen in happy but not surprised faces; perhaps as a result, at all ages, misidentification of surprise as happy was more common for these faces than for the two male faces without this intrusion. The 5-year-olds' higher rates of misidentification of surprise as happy might have been caused by their acute sensitivity to cues to happy expressions and their inability to ignore intrusions as effectively as adults and older children. However, 5-year-olds also made this error for the male faces more frequently than adults and older children (3.3–3.8 vs. 0.0–1.4%) despite there being no intrusion from the lip corner puller. Overall, our results suggest that young children (5- and 7-year-olds) are likely to misread surprised expressions two to three times more often than adults, a misreading that may lead to inappropriate reactions.

Disgust

By 14 months (the youngest age tested), infants appear to understand the meaning of disgusted expressions; they are more likely to search in a box associated with a happy expression than in a box associated with a disgusted expression (Repacholi, 1998). During childhood, sensitivity to the facial expression of disgust develops more slowly than other expressions even when the expression is intense (Camras & Allison, 1985; Durand et al., 2007; Kolb et al., 1992; Markham & Adams, 1992; Vicari et al., 2000; but see Montirosso et al., 2010). Previous studies indicate that 5- to 10-year-olds confuse intense expressions of disgust not only with sadness, as adults do, but also with anger, especially at 5 or 6 years of age (Gagnon et al., 2010; Gosselin & Larocque, 2000; Gosselin & Pelissier, 1996).

Similarly, in the current study, all four age groups misidentified disgust as sadness at a high rate (>25%). The 5-year-olds made this error more often (37.2% of disgust trials for which they chose a non-neutral response) and, unlike the other groups, also sometimes misidentified disgust expressions as angry (4.1 vs. $\leqslant$1%). The high misidentification rates between disgust and sadness may have resulted from the presence of the brow lowerer facial action unit in all four models depicting disgusted expressions. Brow lowerer is normally seen in sad expressions but not in canonical disgusted expressions. However, this interpretation cannot explain the higher incidence of this error in 5-year-olds, who showed poor sensitivity to sad expressions on all three measures.

We found that 7-year-olds need more intensity than adults to detect expression in faces showing disgusted expressions; that is, they have higher thresholds. (The thresholds of 5-year-olds were also higher than those of adults when the calculations of both were based on 10 levels of intensity.) There were no age differences for the recognition of intense expressions of disgust. The fact that 5- and 7-year-olds are as accurate as adults in recognizing intense disgusted expressions but not in recognizing less intense ones may reflect their sensitivity to disgust as a biological response (e.g., to bad food), which tends to be intense, but not to disgust as a moral response, which is not always intense and to which they are likely not exposed often during early childhood. Adults recruit the same neural system for both forms of disgust and use the same muscles to express it (Chapman, Kim, Susskind, & Anderson, 2009). If this analysis is correct, young children may miss the meaning of a mildly disgusted expression signaling a negative moral response to their behavior.

Methodological issues

The developmental patterns observed here are affected by the particular groupings of facial expressions in the forced-choice procedure. Different response alternatives affected the patterns of confusion among facial expressions for two of the three expressions included in both studies (sad and fear) but not for the third expression (happy). In our previous study (Gao & Maurer, 2009), which paired fear with sad and happy, compared with adults, 5-year-olds more frequently misidentified fear as sad even at high intensity. In the current study, in which fear was paired with surprise and happiness, there were no age differences in misidentifications. There was a similar pattern for sadness. All age groups had higher misidentification rates for sad expressions when they were grouped with fearful and happy expressions (Gao & Maurer, 2009) than when they were grouped with disgusted and angry expressions (this study) mainly because of confusion of sadness with fear in the previous study. Different choices of facial expression also affected the thresholds to discriminate sad expressions from neutral. When sad expressions were grouped with only negative expressions (e.g., disgust and anger), all age groups had higher thresholds to detect expression in sad faces compared with the previous study, in which sad faces were grouped with both positive (e.g., happy) and negative (e.g., fearful) expressions. The reason for the elevation in thresholds for sad in the current study is not clear. These differences highlight the importance of testing children with groupings that involve the expected errors seen in adults (e.g., surprise and fear) but also with groupings of expressions that are not expected to be confused (e.g., surprise and happy). Although a procedure involving all seven choices (six basic emotions plus neutral) would get around the grouping issue, such a procedure is not appropriate for children because it would require them to attend to seven choices on each trial. A free labeling procedure in which children provide the verbal label for the expression shown in each picture is another alternative, but it is considered to be a difficult task for children even with a small number of trials with intense expressions (Markham & Adams, 1992; Widen & Russell, 2003).

Besides the use of a forced-choice procedure, another factor that could affect the developmental patterns we observed is the endpoint of each expression at what we called 100% intensity. It is possible that children were as sensitive as adults to our subtle happy expressions simply because the endpoint happy expressions that we used are further away from neutral than other expressions, resulting in larger steps between two adjacent intensity levels for happy expressions than for other expressions. However, this explanation seems unlikely for three reasons. First, an analysis of the physical differences between each expression used and neutral indicates that the differences are not physically larger for the happy continuum. In this analysis, we converted each picture to a grayscale image with 256 levels of intensity. We measured the similarity between each expressive face and its corresponding neutral face by calculating normalized cross-correlations (Gold, Sekuler, & Bennett, 2004) based on the luminance values of the pixels and then averaged the results across the four models. As shown in Fig. 5, for all six expression categories, as intensity increases, the physical difference between the expressive face and the neutral face increases linearly, as shown by the linearly decreasing correlation. The endpoints of the six expression categories have similar physical differences from the neutral face (range of correlation = 0.83 [anger] to 0.87 [happiness]). In fact, the slightly higher correlation between neutral and 100% happy indicates that the endpoint of the happy continuum is physically closer to neutral than the endpoints of other expressions. Second, we selected the endpoint faces based on ratings from adults in a previous study (Palermo & Coltheart, 2004). Those ratings indicate that adults perceive the endpoints we used as not differing substantially in intensity. Specifically, adults had similar mean intensity ratings for the six expressions (on a 7-point scale, averaged across the four models, 6.1 for angry faces, 5.6 for disgusted faces, 5.4 for happy and fearful faces, and 5.2 for sad and surprised faces). Although there are small differences among the perceived intensity of the selected expressions, such differences cannot account for the different developmental patterns found in the current study. For example, the endpoint angry faces were rated as the most intense of the expressions, but the angry continuum was the only expression for which thresholds were still not adult-like at 10 years of age. In contrast, although the rated intensity of the endpoint happy faces is not the highest in the set, children showed early maturation in detecting expression in the happy faces. Third, the analyses did not involve comparison of thresholds across expressions but rather involved comparison of performance with each continuum across age, that is, comparison of thresholds for each expression between children and adults and conclusions about the developmental trajectories, not the absolute thresholds. Therefore, the small differences in physical intensity and perceived intensity of the endpoint faces for the six expression categories are not likely to account for the different developmental patterns for different expressions found in the current study.

A final limitation is that, unlike the current testing conditions, in everyday life facial expressions are dynamic, within specific contexts, and often accompanied by other cues to expressed emotion (e.g., voice, body posture). Had we provided these types of information in the current study, the differences between adults and children might have been smaller, but they also could have been increased if adults are more adept than children at using the additional cues. The benefit from these additional cues may also differ across expressions. Children's ability to use such information remains largely unexplored.

Differences between emotions

For the reasons outlined in the previous section, our main conclusions concern the development of sensitivity to each emotional expression considered on its own. Nevertheless, it is instructive to compare the developmental patterns across expressions. Although we can never eliminate the possibility

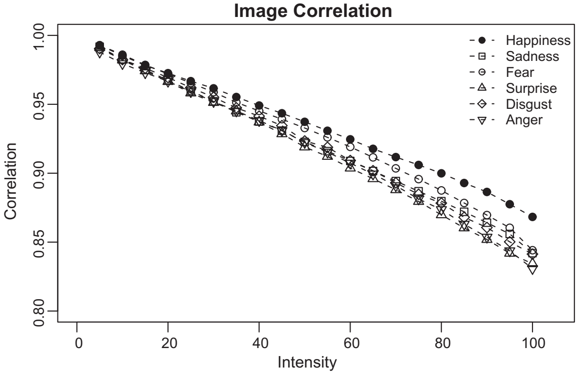

Fig. 5. Mean correlation between each expression at each intensity and neutral based on image pixel information. Shown are the means across the four models.

that the developmental changes in sensitivity to facial expressions in the current study reflect general improvements in memory, attention, and motivation, these factors are not likely to account for the patterns found here given the child-friendly procedure and unlimited viewing time we used in the study and the fact that children as young as 5 years had adult-like thresholds for happy expressions, as they did in our previous study (Gao & Maurer, 2009).

A comparison across expressions tested in the current study and our previous study (Gao & Maurer, 2009) confirms the early development of sensitivity to happy expressions reported in the literature (Camras & Allison, 1985; Durand et al., 2007; Kolb et al., 1992; Markham & Adams, 1992; Vicari et al., 2000; Widen & Russell, 2003) and also suggests that sensitivity to negative expressions develops at different rates for different expressions and different measures. Thresholds become adult-like earlier for surprise (7 years of age) than for fear, sadness, and disgust (10 years, at least with some groupings), with the latest maturity for anger (after 10 years). However, misidentifications show a different pattern: adult-like levels quite early for anger (by 5 years of age) and especially late for sad (after 10 years, at least with some groupings). The different developmental patterns may reflect the amount of exposure to different facial expressions in a child's environment: frequent for happy expressions, intermediate for surprise, and least for anger. Studies of special populations support the hypothesis that exposure influences the development of sensitivity. Neglected children, who are likely to have less exposure to facial expressions than normal developing children, are less accurate at discriminating facial expressions than normal developing children (Pollak, Cicchetti, Hornung, & Reed, 2000). Physically abused children, whose rearing environment is likely to have more angry expressions than usual, have a lower threshold to detect anger in a face than normal developing children (Pollak & Sinha, 2002). Children's early sensitivity to subtle happy expressions found in the current study may be a result of their exposure to happy expressions at a wide range of intensities in the environment. However, exposure alone does not readily account for the patterns among the other expressions (e.g., adult-like thresholds earlier for subtle expressions of surprise than disgust). These differences may instead, or may also, be related to differences among expressions in salience and signal value as children view them in their environment and express them themselves. The environmental factors may also interact with children's changing visuocognitive skills in shaping children's sensitivity to subtle facial expressions. Those visuocognitive skills include the skills that allow children to extract visual information from faces such as acuity and contrast sensitivity (adult-like by 7 years of age [Ellemberg, Lewis, Liu, & Maurer, 1999]), vernier acuity (adult-like by early adolescence [Skoczenski & Norcia, 2002]), contour integration (adult-like by early adolescence [Kovács, Kozma, Fehér, & Benedek, 1999]), and sensitivity to facial feature spacing (continues to develop after 10 years of age [Mondloch, Dobson, Parsons, & Maurer, 2004; Mondloch, Geldart, Maurer, & Le Grand, 2003; Mondloch, Le Grand, & Maurer, 2002; but see McKone & Boyer, 2006, and Pellicano, Rhodes, & Peters, 2006, for adult-like sensitivity on some tasks at a younger age). Improvements in cognitive skills such as perspective taking will also help children to decipher the context, and hence the meaning, of subtle facial expressions (Choudhury, Blakemore, & Charman, 2006).

In conclusion, by using facial expressions at varying intensities, we investigated developmental changes in children's sensitivity to facial expressions of the six basic emotions with multiple measures. The results indicated that children are as sensitive as adults to subtle happy expressions by 5 years of age, whereas they show a longer developmental course for negative facial expressions. Future studies could use the stimuli and technique described here to study changes in the neural mechanisms underlying the perception of facial expressions. The stimuli and technique developed in the current study could also be used to study special populations such as children with autism, neglected or abused children, and children with abnormal visual experience. Future studies could also adapt the current technique to study the effect of familiarity (familiar vs. unfamiliar faces), race (own-race vs. other-race faces), age (children's faces vs. adults' faces), or dynamic emotion on children's sensitivity to facial expressions.

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