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Developmental changes in face processing skills

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Abstract

Expertise in processing differences among faces in the spacing among facial features (second-order relations) is slower to develop than expertise in processing the shape of individual features or the shape of the external contour. To determine the impact of the slow development of sensitivity to second-order relations on various face-processing skills, we developed five computerized tasks that require matching faces on the basis of identity (with changed facial expression or head orientation), facial expression, gaze direction, and sound being spoken. In Experiment 1, we evaluated the influence of second-order relations on performance on each task by presenting them to adults ($N = 48$) who viewed the faces either upright or inverted. Previous studies have shown that inversion has a larger effect on tasks that require processing the spacing among features than it does on tasks that can be solved by processing the shape of individual features. Adults showed an inversion effect for only one task: matching facial identity when there was a change in head orientation. In Experiment 2, we administered the same tasks to children aged 6, 8, and 10 years ($N = 72$). Compared to adults, 6-year-olds made more errors on every task and 8-year-olds made more errors on three of the five tasks: matching direction of gaze and the two facial identity tasks. Ten-year-olds made more errors than adults on only one task: matching facial identity when there was a change in head orientation (e.g., from frontal to tilted up). Together, the results indicate that the slow development of sensitivity to second-order relations causes children to be especially poor at recognizing the identity of a face when it is seen in a new orientation.

Keywords: Face processing; Perceptual development; Visual perception; Inversion effect; Second-order relations

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Introduction

Adults are 'experts' in face processing: they can recognize thousands of individual faces rapidly and accurately, and they can easily decipher various cues, such as emotional expression and direction of gaze (Bahrick & Wittlinger, 1975; see Bruce & Young, 1998 for a review). Many face processing skills emerge during early infancy, including differentiation of some emotional expressions (Barrera & Maurer, 1981; Young-Browne, Rosenfeld, & Horowitz, 1977); discrimination of the direction of eye gaze (Hains & Muir, 1996; Hood, Willen, & Driver, 1998; Vecera & Johnson, 1995); formation of a mental prototype of a group of faces (de Haan, Johnson, Maurer, & Perrett, 2001); and recognition of a person's face posing with different head orientations (Pascalis, de Haan, Nelson, & de Schonen, 1998). Nevertheless, school-aged children are not as proficient as adults at processing faces, particularly in recognizing facial identity. Recognition of faces in a study set increases dramatically between 7 and 11 years of age, but even 14-year-olds make more errors than adults (Carey, Diamond, & Woods, 1980). Even in matching tasks, which eliminate memory demands, performance improves dramatically between 4 and 11 years of age (Bruce et al., 2000; Carey & Diamond, 1994; Carey & Diamond, 1977; Mondloch, Le Grand, & Maurer, 2002).

Various studies have attempted to determine the nature of children's immaturity in identifying faces. One reason may be that they rely more on superficial external characteristics—like hair style and colour—whereas adults rely more on internal features that are less likely to change with lighting, the donning of a hat, or a trip to the hairdresser. Indeed, 6- and 8-year-olds are influenced more by paraphernalia (e.g., glasses, hats) than are 10-year-olds and adults when matching unfamiliar faces (Carey & Diamond, 1977; Freire & Lee, 2001), although the influence is reduced when the faces presented are less similar (Baenninger, 1994). Research has shown that adults rely more on internal facial features than on external features (e.g., hair) when recognizing familiar faces (Ellis, Shepherd, & Davies, 1979). In contrast, children younger than 7 years of age rely more on external features; it is only when children are between 9 and 11 years of age that they show the adult-like pattern (Campbell & Tuck, 1995; Campbell, Walker, & Baron-Cohen, 1995; Want, Pascalis, Coleman, & Blades, 2003). Children's reliance on external features may extend to the recognition of unfamiliar faces as well. Five- to 6-year-olds performed well (78% correct) on an identity task in which the target and foil faces were similar but had visible hair, but were near chance on another identity task in which the target and foil faces were dissimilar but had their hair masked (55% correct). On the latter task, only 6 of 30 children performed above chance (Bruce et al., 2000; but see Newcombe & Lie, 1995; Young, Hay, McWeeny, Flude, & Ellis, 1985 for different results from both adults and children in simultaneous matching tasks and when the task requires matching unfamiliar faces).

Children's immaturity in recognizing faces may also come from their difficulty in processing the spacing among the internal features of the face, or *second-order relations*. All faces share the same ordinal relations of features (two eyes above a nose, which is above a mouth; Diamond & Carey, 1986) that differ from the first-order relations of other objects. These *first-order relations* facilitate detecting that a stimulus is a face but, because they are common to all faces, are insufficient for the recognition of individual faces. Recognizing faces requires processing second-order relations (small differences between individuals in the spacing among the facial features, e.g., distance between the eyes or between the mouth and chin), and/or differences among individual faces in the shape of individual features (e.g., eyes, mouth, and chin) (reviewed in Maurer, Le Grand, & Mondloch, 2002). The most direct evidence that children are especially immature in processing second-order relations comes from studies in which a set of faces has been created that differ from one another mainly in only one of the above dimensions. For example, Mondloch et al. (2002) modified a single face (called 'Jane') to create 12 new versions (called Jane's sisters)—four that differed in the shape of internal features (featural set), four that differed in the shape of the external contour (contour set) and four that differed in the spacing among internal features (spacing set). Adults and children, aged 6, 8, and 10 years, were presented with pairs of faces sequentially and asked to make same/different judgments. On the spacing set, all groups of children made more errors than adults. In contrast, on the external contour and featural sets, children at all ages were almost as accurate as adults. Similarly, children aged 4–7 years performed only slightly better than chance when asked to detect a target face among distracters that differed only in the spacing of features (Freire & Lee, 2001); their accuracy was higher when the target differed from the distracters in the shape of individual features.

Studies that measure the effect of inversion on face recognition also suggest that children rely less than adults on second-order relations. Inversion disrupts adults' discrimination (Freire, Lee, & Symons, 2000; Le Grand, Mondloch, Maurer, & Brent, 2001; Mondloch et al., 2002) and recognition (Leder & Bruce, 2000) of faces that differ in the spacing of facial features much more than recognition of faces that differ in the shape of individual features, and it disrupts adults' recognition of faces more than their recognition of other classes of objects (e.g.,Yin, 1969). Collectively, these studies suggest that adults' expertise in recognizing upright faces depends, in part, on their greater ability to process second-order relations in upright than in inverted faces (see Collishaw & Hole, 2000 for evidence that featural processing contributes to the processing of facial identity in both upright and inverted faces). In contrast, judgments of facial identity by children aged 6 and 8 years often are not impaired by inversion when targets and foils are two different faces (i.e., when both featural and spacing cues are available) (Carey & Diamond, 1977; but see Brace et al., 2001 for a simpler task in which children's reaction times show the classic inversion effect from the age of 5 years). Although even 6-year-olds show an inversion effect when making same/different judgments for 'Jane' and her 'sisters' (Mondloch et al., 2002), it is not until 10 years of age that the inversion effect is larger for the spacing set than it is for the featural and external contour sets, as it is in adults—a pattern suggesting that younger children are unable to do effective processing of second-order relations.

Perhaps because children rely less than adults on second-order relations and more than adults on external contour/paraphernalia, they have especial difficulty matching faces that differ in point of view, paraphernalia, facial expression or lighting (Benton & Van Allen, 1973 as cited in Carey et al., 1980; Ellis, 1992). Such changes render second-order relations more important because faces no longer can be matched accurately based on the appearance of individual features. This hypothesis also explains why children perform better on an identity task in which faces are similar but hair is visible than they do when faces are dissimilar but hair is masked (Bruce et al., 2000). Masking the hair removes an important cue for children and increases the importance of processing second-order relations.

Children's performance on other face-processing tasks may also vary with the extent to which individual features versus the spacing among features provide critical information. Five- to six-year-olds perform near ceiling when asked to identify which of two faces is demonstrating a particular facial expression, sound being mouthed, or direction of gaze (Bruce et al., 2000). Their good performance on these tasks may be due to the ability to identify the correct target based on an isolated feature (e.g., mouth shape) rather than having to process the spatial relations among multiple features.

The purpose of our study was to relate the development of face processing skills that are used in daily life (e.g., recognizing a face's identity despite changes in head orientation or emotional expression) to evidence that children's immaturities in face processing are due to their relying on the shape of individual features, external contour, and paraphernalia more than the spacing among internal features. To do so, we administered the same five tasks to adults and to three groups of children. In Experiment 1 we measured the extent to which each task tapped second-order relational processing by presenting the stimuli in an upright orientation to one group of adults and in an inverted orientation to another group. Because inversion disrupts recognition based on the spacing of internal features more than recognition based on the shape of individual features (Freire et al., 2000; Leder & Bruce, 2000; Mondloch et al., 2002), we hypothesized that adults would show the greatest inversion effect for the tasks requiring sensitivity to second-order relations. In Experiment 2, we administered the same five tasks in the upright orientation to three groups of children (aged 6, 8, and 10 years) and evaluated the hypothesis that they would be most immature on tasks that are influenced by sensitivity to second-order relations, as determined in Experiment 1.

We created five tasks in which participants were asked to indicate which of three test faces matched a target face on the basis of identity (with changed facial expression or head orientation), facial expression, gaze direction, and sound being spoken—all skills that are used in daily social interactions. The test battery was adapted from one that showed differential deficits across tasks both in children with congenital brain damage and in autistic children (Gepner, de Gelder, & de Schonen, 1996; Mancini, de Schonen, Deruelle, & Massouller, 1994). The study was similar to Bruce et al. (2000), except that we administered the same tasks to all age groups and compared children's performance to that of adults rather than to that of 10-year-olds because several studies have shown that even 10-year-olds have immature face-processing skills (Carey & Diamond, 1994; Carey et al., 1980; Mondloch et al., 2002). We presented adults with both upright and inverted faces in order to determine which tasks tap sensitivity to second-order relations. Another difference was that we measured reaction time as well as accuracy. Although overall age differences in reaction time are not of theoretical interest here, differences across tasks in the extent to which children are slower than adults can provide important information. For example, if on all tasks, children either are as accurate as adults or make more errors than adults, an analysis of reaction time may reveal differential maturity. Even if children have adultlike accuracy on only a subset of tasks, it is important to determine that their adultlike accuracy is not a reflection of speed-accuracy trade-offs. Finally, the two studies differ in that our target faces were those of adults rather than of children.

Experiment 1

To evaluate the contribution of sensitivity to second-order relations to each of the five tasks, we took advantage of the finding that inversion affects the ability to discriminate faces based on second-order relations more than the ability to discriminate faces based on the shape of individual features. Since the classic study by Yin (1969), it has been known that inversion impairs adults' ability to identify faces much more than their ability to identify other mono-oriented objects (unless they have developed face-like expertise for another homogeneous category—e.g., Diamond & Carey, 1986; Gauthier, Skudlarski, Gore, & Anderson, 2000). Recent studies indicate that, although inversion also affects the ability to process individual features (e.g., Leder & Bruce, 2000), it chiefly impairs sensitivity to second-order relations. For example, under some conditions adults' accuracy in making same/different judgments about faces presented sequentially decreases when faces are inverted regardless of whether faces differ in the spacing of internal features, the shape of internal features, or the shape of the external contour; however, the size of the inversion effect is always much larger for faces that differ in the spacing among internal features (Freire et al., 2000; Mondloch et al., 2002; see also Barton, Keenan, & Bass, 2001; Leder & Bruce, 2000). This pattern suggests that processing of second-order relations is particularly sensitive to inversion. That conclusion is consistent with evidence that adults can recognize blurred faces with reasonable accuracy, but are severely impaired if the faces are simultaneously blurred and inverted—presumably because blurring removes featural information and inversion disrupts sensitivity to second-order relations (Collishaw & Hole, 2000). Similarly, adults' ratings of distinctiveness and bizarreness drop when faces with distorted second-order relations are inverted, but there is no such drop for faces with distorted features (Leder & Bruce, 1998; Murray, Yong, & Rhodes, 2000). Thus we reasoned that differences in the size of the inversion effect across tasks would reflect differences in the extent to which each task taps sensitivity to second-order relations. We wanted to determine which face-processing skills are most dependent upon sensitivity to second-order relations in order to determine, in Experiment 2, whether it is those skills that are slowest to develop.

Method

Participants

The participants were two groups of 24 Caucasian adults, aged 18–28 years. Adults were undergraduate students participating for credit in a psychology course at McMaster University and half of the participants in each group were female. Because one goal of our research is to study the effects of early visual deprivation on various face-processing skills (e.g., Geldart, Mondloch, Maurer, de Schonen, & Brent, 2002; Le Grand et al., 2001), we wanted to include in the normative data results only from participants with normal visual histories. Consequently, none of the participants had a history of eye problems, and all met our criteria on a visual screening exam. Specifically all participants had Snellen acuity of at least 20/20 in each eye without optical correction, worse acuity with a +3 diopter lens (to rule out farsightedness of greater than 3 diopters), fusion at near on the Worth Four dot test, and stereoacuity of at least 40 arc seconds on the Titmus test. In addition, all participants reported being right-handed. An additional 7 participants were tested but excluded from the final analysis because they failed visual screening.

Stimuli

Gray scale digitized images of Caucasian male and female faces, aged between 18 and 28 years, were taken using a Chinon ES-3000 electronic camera under standard lighting conditions (see Geldart, 2000). To encourage processing of the internal portion of the face and to discourage reliance on non-face features, models wore a surgical cap covering their hair and ears and they removed all jewelry and glasses. Faces were photographed from 1 m, with a 3× zoom lens set so that each neutral face measured 11 cm (6.3 visual degrees from 100 cm) from the top of the forehead to the bottom of the chin. We used Adobe Photoshop to remove natural markings (e.g., freckles, moles), to center the images, and to crop them to a size of 10 cm wide and 15 cm high ($5.7° \times 8.6°$ from 100 cm).

Apparatus and procedure

After the procedures were explained, we obtained written consent. The participant sat in a darkened room with his/her eyes 100 cm from the monitor. The stimuli were presented on a monochrome Radius 21-GS monitor controlled by a Macintosh LC-475 computer and Cedrus Superlab software. The experimenter initiated each trial by pressing a key on the keyboard and participants signaled their responses via a joystick (three tasks) or by pointing (two tasks). One group of adults was tested with stimuli in an upright orientation; the other group of adults was tested with stimuli in an inverted orientation.

There were six test trials for the training task and for each of five experimental tasks. Each trial contained four faces of the same sex. With the exception of the training task, those four faces were matched closely on external contour, complexion, and color of eyes and eyebrows. On each trial, a target face appeared at the top of the computer screen for 2 s, and following an inter-stimulus interval of 396 ms, three test faces, which were the same size as the target face, appeared side-by-side at the bottom of the screen. The test stimuli were presented after the target disappeared in order to prevent participants from analytically comparing the features of the target and test stimuli, but the inter-stimulus interval was kept brief to minimize memory demands. The tester emphasized accuracy but asked the participants to respond as quickly as possible. The test faces disappeared once a response was made.

All tasks, including the training task, began with three practice trials. For each task, half of the six test trials used male faces and half female faces, and there was at least one trial in which the matching face was positioned on the left, in the middle and on the right of the screen. We did not counterbalance the location of the matching face across the six trials of each task because we did not want participants to be able to guess the correct location for the last one or two trials. Instead, we counterbalanced the correct location across all 36 trials that made up the six tasks (training + 5 tasks). In addition, we created a second version of each task that differed in the number of correct responses in the left, middle, and right, but otherwise followed the same constraints, and then randomly assigned participants to one of the two versions of each task.

The tasks are described in the order in which they were presented, which was the same for all participants and based on the order that adults found easiest during pilot work. Pilot participants reported that it was easier to understand the instructions for matching when the identity tasks came first, presumably because the procedure began with a training task of the same type. Participants did not receive feedback, except for the first practice trial of each task.

Training task. The training task used faces facing forward (i.e., en face) with a neutral facial expression. The participant was asked to choose the test face that matched the target in identity. The training task was easier than the experimental tasks because, unlike the experimental tasks, one of the test faces was a duplicate image of the target face, some of the faces had unique markings (e.g., moles, freckles), and the faces were not matched on chin contours, complexion, or coloring of eyes and eyebrows. Any participant who failed the criterion of at least 5/6 correct was allowed to repeat the training task up to three times, in each case with a different version that re-positioned the correct matching face.

Task 1: Identity/changed facial expression. Task 1 used faces posing with their head and eyes frontal and with one of four emotional expressions: neutral, surprise, happy, and disgust. Each trial used all four expressions: the target face had one facial expression (e.g., happy) and was followed by the same person's face but with a different facial expression (e.g., neutral) and two novel faces, with the two remaining expressions. The participant was asked to signal which test face had the same identity as the target despite changed facial expression. Stimuli from a sample trial are presented in Fig. 1A.

Task 2: Identity/changed head orientation. Task 2 used faces posing with a neutral facial expression and with both their head and eyes frontal, 45° to the right, 45° to the left, 45° up or down. Each trial used four head orientations: the target face posed with one head orientation (e.g., right), and was followed by the same face but with a different head orientation (e.g., left) and two novel faces, posing with two remaining head orientations (e.g., down, up) (see Fig. 1B). The participant was asked to indicate the test face with the same identity as the target despite changed head orientation.

Task 3: Facial expression. Task 3 used faces posing with their head and eyes frontal and with one of four emotional expressions: neutral, surprise, happy, and disgust. Each trial had three possible facial expressions: the target face with one expression (e.g., surprise) was followed by one novel face posing with the same expression

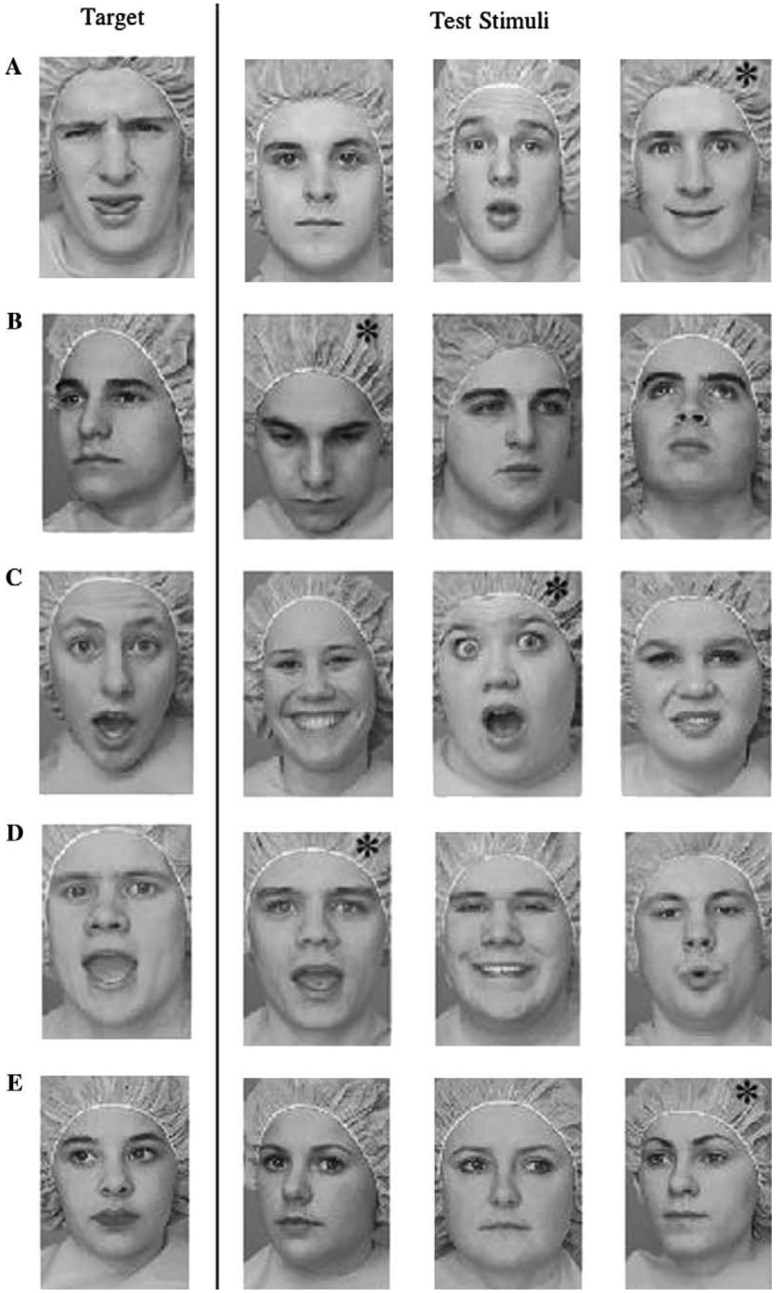

Fig. 1. An example of the stimuli presented in each of the five tasks: identity/changed facial expression (Panel A); identity/changed head orientation (Panel B); facial expression (Panel C); lip reading (Panel D); direction of eye gaze (Panel E). (*Note*: * indicates the correct response.)

(i.e., surprise) and two novel faces, each with one of the remaining expressions (see Fig. 1C). The participant was asked to indicate which test face had the same facial expression as the target.

Task 4: Lip reading. Task 4 used faces posing with their head and eyes frontal and pronouncing one of three long vowels: a, e, u. Each trial used all three vowels: the target face mouthing one vowel (e.g., u), was followed by one novel face mouthing the same vowel, and two novel faces mouthing the two remaining vowels. The participant was asked to indicate which test face was mouthing the same vowel as the target (see Fig. 1D).

Task 5: Direction of gaze. Task 5 used faces posing with a neutral expression, in one of six possible combinations of gaze and head orientations: eyes and head frontal; eyes and head 30° to the left (or right) of the camera; eyes frontal and head 30° to the left; and eyes 30° to the right (or left) and head frontal. Each trial contained four types of gaze/head direction: the target face posed with one gaze direction and head orientation (e.g., eyes 30° left; head frontal), and was followed by one novel face with the same gaze direction as the target (i.e., 30° left) but a different head orientation (e.g., 30° left), and two novel faces with a different gaze direction from the target and the same or different head orientation as the target (e.g., eyes frontal, head 30° right; eyes 30° right, head frontal). The participant was asked to indicate the test face having the same direction of gaze as the target, and to ignore any changes in the direction of the head (see Fig. 1E).

For three of the tasks (1, 3, and 4) the participant was instructed to indicate which of the three test faces matched the target face by moving the joystick either to the left, to the right, or forward (if the matching face was in the middle). However, during pilot work, adults made errors on tasks 2 and 5 by moving the joystick toward the direction in which the matching face was oriented rather than its location on the screen. Therefore, for tasks 2 and 5 participants were asked to indicate the location of the matching face verbally or by pointing, rather than by using the joystick, and the tester coded their choices.

Results

All adults in both groups met the criterion of 5/6 correct responses on the training task. For each participant, we calculated the proportion of responses that were correct on each of the five tasks, and the median reaction time on correct trials for the three tasks for which participants coded their own responses using the joystick: identity/changed facial expression, facial expression, and lip reading. To reduce the effect of trials with outlying values, we calculated the median reaction time, rather than the mean. To see if inversion had a differential effect across tasks, we conducted ANOVAs on the proportion of correct responses and median response time, with orientation as the between-subjects factor and task as the within-subjects factor. Significant interactions were explored with analyses of simple effects.

Adults' accuracy and reaction times on upright versus inverted trials are shown in Figs. 2 and 3, respectively. Figs. 2 and 3 show that adults were less accurate and slower when matching faces on facial identity than when matching faces based on emotional

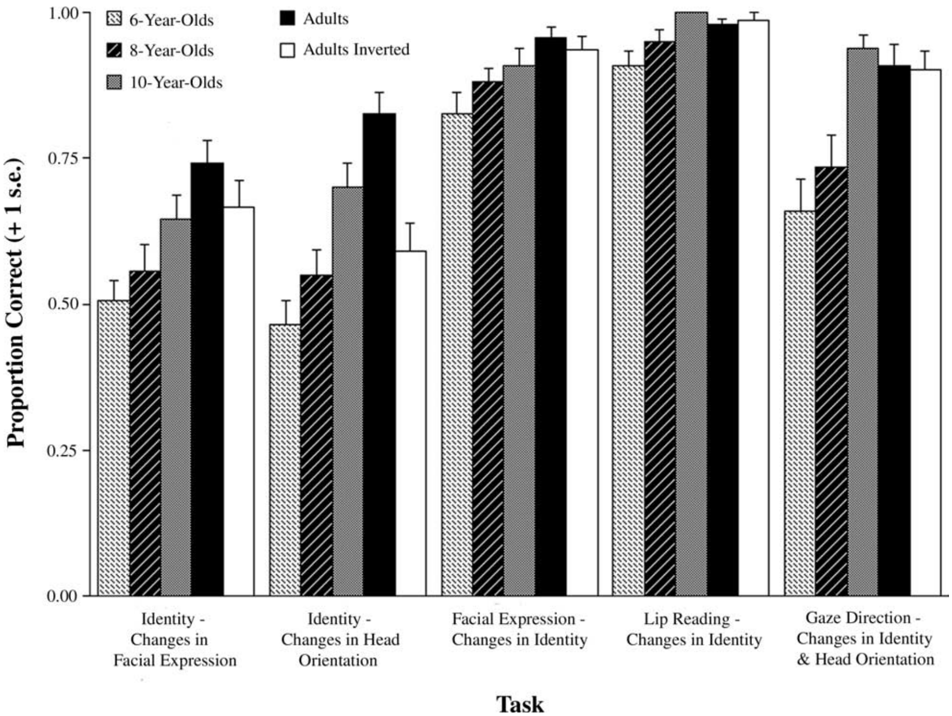

Fig. 2. Mean accuracy (+1*SE*) when the stimuli were presented upright to children in Experiment 2 and upright and inverted to adults in Experiment 1.

expression, direction of eye gaze, or sound being spoken. The ANOVA on accuracy revealed a significant effect of orientation, $F(1,46) = 10.5$, $p < .01$, and task, $F(4,46) = 33.178$, $p < .01$, and a significant orientation × task interaction, $F(4,184) = 4.63$, $p < .01$. Analyses of simple effects were used to determine the effect of orientation for each task. Inverting the stimuli decreased accuracy for only one of the five tasks: matching identity/point of view, $t(46) = 3.85$, $p < .01$; all other *p*s $> .10$. On this task only, adults were more accurate when the stimuli were upright ($M = .83$) than when stimuli were inverted ($M = .59$). The ANOVA on median reaction times for correct trials revealed a significant effect of task, $F(2,92) = 100.05$, $p < .01$, and a significant orientation × task interaction, $F(2,92) = 3.38$, $p < .05$. There was no main effect of orientation, $p > .10$. Fig. 3 shows that adults' reaction times were longer on matching identity/point of view than on matching emotional expression and sound being mouthed. Analyses of simple effects were used to determine the effect of orientation for each task; none of the comparisons were significant, all *p*s $> .10$.

Discussion

Adults' accuracy was significantly lower for the inverted faces than for the upright faces for only one of the five tasks: matching identity despite changes in head

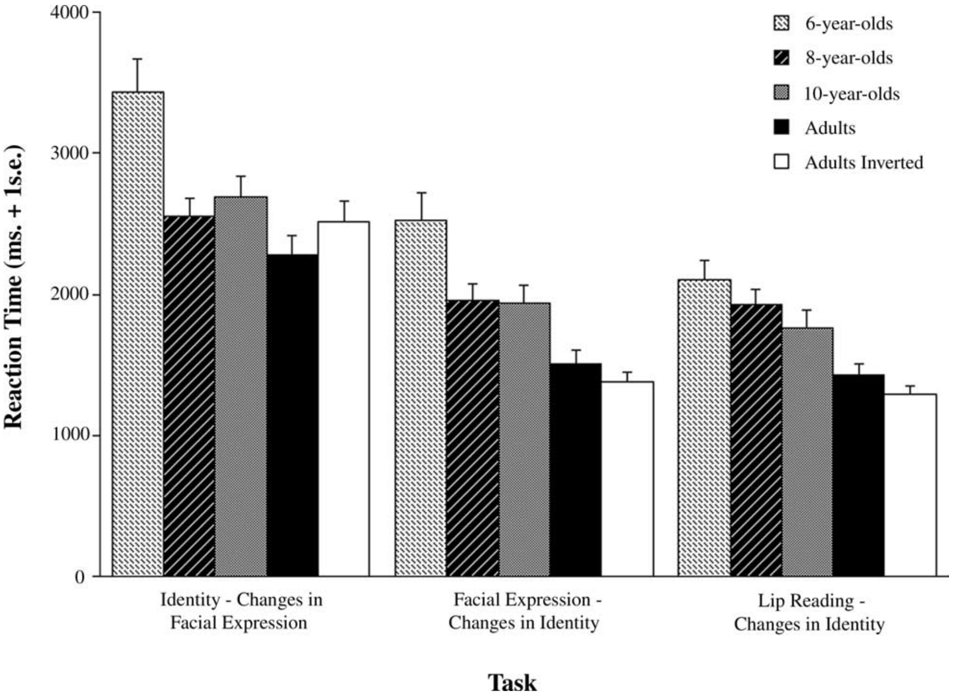

Fig. 3. Mean reaction time (ms. + 1*SE*) on correct trials for each age group when the stimuli were presented upright to children in Experiment 2 and upright and inverted to adults in Experiment 1. Reaction times were available for only three of the tasks because on the remaining tasks participants were asked to point to the matching stimulus (see text).

orientation. The pattern of results for inversion cannot be explained by task difficulty. As shown in Fig. 2, adults were as accurate on matching identity despite changes in head orientation as they were on matching identity despite changes in emotional expression when the faces were upright, yet inversion decreased accuracy only on the former task. Although inversion can interfere with featural processing, previous research has shown that the deleterious effect of inversion is larger for tasks that tap sensitivity to second-order relations (see Maurer et al., 2002 for a review). The results for inversion are consistent with an analysis of the tasks. When a face is seen from the side versus the front, individual features such as the nose or an eye change shape or even disappear, whereas the spacing of any visible features remains relatively invariant (see Fig. 1A). Based on this observation, it is not surprising that adults' accuracy in matching facial identity despite changes in head orientation dropped from 83 to 59% when the faces were inverted—a manipulation that disrupts processing of spacing information. Changing emotional expression alters the shape of the external contour and internal features less than changing head orientation, rendering featural processing more useful. Thus, it is not surprising that inversion caused only a slight, and non-significant, decrease in accuracy for matching identity despite changed emotional expression. In the present study, the tasks requiring the matching of emotional expression or lip reading could be solved by attending to individual features, such as the shape of the lips, and there was little overlap in the shape of individual features (e.g., eyes, mouth) across expressions (see Fallshore & Bartholow, 2003; McKelvie, 1995, for evidence of an effect of inversion on the discrimination between facial expressions which share similar eye or mouth shape [e.g., fear and surprise]). Likewise, matching direction of eye gaze requires the processing of relatively isolated features. Thus, although second-order relations may contribute to performance on each of these tasks when the stimuli are upright, it is not surprising that the accuracy in matching based on emotional expression, direction of gaze, or sound being mouthed was not affected by inversion.

In the present study participants had 2 s to view the model face and the test stimuli remained on until the participant made a response. Had the presentation times been shorter, inversion might have affected adults' accuracy on all tasks to some extent, even those that they tap mainly featural processing (see Mondloch et al., 2002, for evidence of a small inversion effect for featural processing in speeded tasks). Nevertheless, it is clear that, under our testing conditions, inversion has a larger effect on adults' ability to recognize identity despite changes in head orientation than on any of the other tasks and hence that successful performance on that task is most dependent on sensitivity to second-order relations.

Experiment 2

Two previous studies (Freire & Lee, 2001; Mondloch et al., 2002) reported that the ability to match facial identity becomes adult-like earlier when faces differ only in the shape of internal features (e.g., the eyes) or only in the external contour than when faces differ only in the spacing among features, that is, second-order relations. The purpose of Experiment 2 was to test the implications of the slow development of sensitivity to second-order relations on face processing skills that are used in daily life. In Experiment 2 we tested three groups of children (6-year-olds, 8-year-olds, and 10-year-olds) on the upright versions of the same face-processing tasks and compared their performance to that of the adults tested with upright stimuli in Experiment 1. We hypothesized that performance on matching facial identity despite changes in head orientation would develop more slowly than performance on all other tasks because matching identity despite changed head orientation is most dependent on sensitivity to second-order relations (see Experiment 1).

Method

The participants consisted of three groups of 24 Caucasian children: 6-year-olds (±3 months), 8-year-olds (±3 months), and 10-year-olds (±3 months). Half of the participants in each group were female. Children were recruited from names on file of mothers who had volunteered them at birth for later study and through informal contacts. The inclusion criteria for children were identical to the criteria for adults in Experiment 1, with one exception. Six-year-olds were required to have visual acuity of at least 20/25 on the Goodlight Crowding test, rather than Snellen acuity of at least 20/20. An additional 26 participants were tested, but excluded from the final analysis: 20 failed visual screening (3 6-year-olds, 13 8-year-olds, and 4 10-year-olds), 5 failed to meet the criterion for the practice task (3 6-year-olds, 2 8-year-olds), and 1 (a 6-year-old) was excluded due to equipment failure. All participants were right-handed according to self/parent-report. The procedure was identical to that used in Experiment 1 except that all stimuli were presented upright.

Results

To measure age differences in the ability to perform each task we conducted ANOVAs on the proportion correct responses and median response time, with age as the between-subjects factor and task as the within-subjects factor. We included the data from adults tested with upright faces in Experiment 1 in this analysis. Significant interactions were explored with analyses of simple effects. We followed up significant effects of task with Fisher's PLSD and significant effects of age with Dunnett's t tests (one-tailed) comparing each age group of children to the adult group.

Fig. 2 shows the mean accuracy for each age group for each of the five tasks. Although the younger age groups performed more poorly than the adults on all five tasks, the figure reveals greater change with age for the two identity tasks and direction of gaze than for matching facial expression or lip reading. These observations were confirmed by the statistical analyses. The ANOVA on accuracy revealed main effects of age, $F(3,92) = 22.09$, $p < .001$, and task, $F(4,368) = 91.68$, $p < .001$, and an interaction between age and task, $F(12,368) = 3.24$, $p < .002$. Analyses of simple effects revealed main effects of age for each of the five tasks, all ps $< .01$; however the age at which performance became adult-like varied. Dunnett's t tests showed that 6-year-olds made more errors than adults on each of the five tasks, all ps $< .01$. Eight-year-olds made more errors than adults on three of the five tasks: they were less accurate in identity/changed facial expression, identity/changed head orientation, and matching gaze direction, all ps $< .01$, but not in matching either emotional expression or lip reading, ps $> .05$. Ten-year-olds made more errors than adults on only one task: matching faces' identity despite changed head orientation, $p < .05$.

The ANOVA of reaction times revealed main effects of age, $F(3,92) = 15.67$, $p < .001$, and task, $F(2,184) = 63.183$, $p < .001$, but no age $\times$ task interaction, $p > .10$. The lack of age $\times$ task interaction means that reaction times do not provide additional evidence of differential rates of development across task. Overall differences between age groups are not of theoretical interest because they could reflect age differences in general speed of processing, motor systems, and/or a number of other systems. As shown in Fig. 3, reaction times were longer for both identity tasks despite changes in facial expression, $p < .001$, and matching facial expression, $p < .05$, than for lip reading. Because reaction times were not shorter on matching faces' identity/changed facial expressions than on the other two tasks at any age (see Fig. 3), 8-year-olds' poorer performance on matching faces' identity/changed facial expressions cannot be attributed to a speed-accuracy trade-off.

Discussion

The results from Experiment 2 demonstrate different developmental patterns for the various face-processing tasks. Although 6-year-olds made more errors than adults on all five tasks, inspection of Fig. 2 indicates that their performance was already nearing adult levels for the tasks involving matching facial expression and lip reading, and 8-year-olds were as accurate as adults on those two tasks, and only those two tasks—a pattern that is consistent with that reported by Bruce et al. (2000). In the present study, improvements with age were slower for direction of eye gaze: there was a large increase in accuracy between 8 and 10 years of age, at which point children reached the adult level of expertise. There was a similar pattern for matching identity despite change in facial expression. The slowest development occurred for matching identity despite changes in head orientation: 6-year-olds were only slightly above chance on this task and 10-year-olds made more errors than adults only on this task. These results are consistent with previous studies that have shown poor performance by children on tasks that require recognizing faces' identity despite changes in head orientation, lighting, or facial expression (Benton & Van Allen, 1973, as cited in Carey et al., 1980; Bruce et al., 2000). Differences in developmental patterns across tasks do not appear to be due to speed/accuracy trade-offs, but may—in part—be attributable to differences in task difficulty. As shown in Fig. 2, adults made more errors on the two identity tasks than on the remaining tasks and made fewest errors on matching facial expression and lip reading. Thus, 8-year-olds made more errors than adults on the two tasks that adults found most difficult, and 10-year-olds made more errors on one of those tasks.

It is possible that a different pattern of development would be revealed under different conditions (e.g., with a more difficult lip-reading task). However, differences in task difficulty do not explain completely the pattern of differences between children and adults. First, adults were as accurate when matching identity/changes in head orientation as they were when matching identity/changes in emotional expression, and yet 10-year-olds made more errors than adults on only one of those tasks (identity/changes in head orientation). Second, adults' performance on the three non-identity tasks (facial expression, lip reading, and eye gaze) did not differ, but 8-year-olds made more errors than adults on only one of these tasks—matching eye gaze despite changes in head orientation. Additional differences between the tasks must underlie the observed differences in rate of development.

In a previous study, we showed that 6-year-olds are adult-like in their ability to discriminate faces based on external contour and nearly as accurate as adults in discriminating faces based on the shape of internal features. The ability to discriminate faces based on the spacing among internal features develops more slowly, with children making more errors than adults even at ages 10, 12, and 14 (Mondloch et al., 2002; Mondloch, Le Grand, & Maurer, in press). The present study demonstrates that the slow development of sensitivity to second-order relations affects children's ability to match facial identity through changes in head orientation—it was only on this task that 10-year-olds made more errors than adults. The fact that, in Experiment 1, adults' accuracy decreased on matching identity despite changes in head orientation when stimuli were inverted but did not decrease on any other task shows that matching identity/changed head orientation taps sensitivity to second-order relations more than the other tasks. In contrast, children as young as 6 were almost adult-like on the two tasks—matching emotional expression and lip reading—which had reliable cues in individual internal and external features. That these tasks can be solved based on processing individual features is supported by the finding that adults were as accurate on these two tasks when the faces were inverted as when they were upright (see Experiment 1).

Inversion did not affect adults' performance on the two other tasks on which 8-year-olds made more errors than adults—direction of eye gaze and matching identity/changed expression, a result that suggests that processing the shape of individual features was sufficient for solving these tasks. Mondloch et al. (2002) reported that although young children were almost as accurate as adults in discriminating faces based on the shape of internal features (eyes, mouth), there was a small, but significant difference in accuracy between 8-year-olds ($M = 83\%$) and adults ($M = 89\%$). Thus it is not surprising that 8-year-olds differ from adults, even when adults can solve a task by featural processing, especially when the task requires the processing of some features and the ignoring of others. To use a featural strategy for matching identity/changed expression, it is necessary to discount some featural differences that are associated with changed facial expression (e.g., change in shape of the mouth, eyes, and chin) while attending to the similarity of other featural properties that indicate a face's identity (e.g., shape of nose and hair contour; abstracted shape of other features with expression discounted). Previous studies have indicated that children may have difficulty ignoring cues (e.g., paraphernalia) that are irrelevant to identity (Carey & Diamond, 1977; Freire & Lee, 2001).

Children aged 6 and 8 may have made more errors than adults on matching direction of eye gaze because they were unable to ignore changes in head orientation. Bruce et al. (2000) found higher accuracy (87%) for decoding direction of gaze in 5- to 6-year-olds than we did (66%), a difference that is consistent with this interpretation. Bruce et al. (2000) tested children's sensitivity to eye gaze in two ways. In one task, the child was asked to indicate which of two faces was looking at him/her. On 75% of the trials, head orientation was either consistent with eye gaze or irrelevant (e.g., both faces were shown in the 3/4 view). In the other task, the child was shown 3 faces simultaneously and asked which of the two faces in the bottom row was looking in the same direction as the face on the top—which was always looking at the child. For half of the trials the identity of the face was the same for all three faces. Our task differed in several ways: the model face disappeared before the test faces were presented; there were two distracters instead of one; none of the test faces matched the model in identity; the correct response did not always involve the face that was looking at the participant; and head orientation of the correct response was always different from that of the model. All of these factors would increase task difficulty and may have contributed to children being misled by head orientation.

In summary, our results are consistent with a growing literature showing that children's performance on face perception tasks is more adult-like when the tasks can be solved by attending to the shape of individual features (e.g., matching identity/

changes in emotional expression, matching emotional expression, lip reading) than when matching requires processing second-order relations (e.g., matching identity/changes in head orientation). Our results also are consistent with previous studies demonstrating children are distracted by paraphernalia. Children make more errors on gaze direction tasks when they are required to ignore changes in head orientation than they do when head orientation is either consistent with eye gaze or provides irrelevant information (because head orientation is similar across targets and distracters; e.g., Bruce et al., 2000).

These data are particularly interesting in light of previous studies in which we reported that patients who were deprived of early visual input due to bilateral congenital cataract perform much like 10-year-olds: they make more errors than visually normal controls on only one of the five tasks—matching identity/changes in head orientation (Geldart et al., 2002)—and they have deficits in processing the spacing among facial features but not the shape of individual features (e.g., eyes, mouth, and chin [Le Grand et al., 2001]). Consistent with these previous studies, Experiment 2 indicates the real-world consequences of the slow development of sensitivity to second-order relations. Like visually deprived patients, young children are able to decode facial signals like emotional expression, direction of gaze, and sound being mouthed, at least when the differences are not subtle and viewing time is in the range of seconds. However, they will have difficulty recognizing a person's identity when processing of second-order relations is necessary because they cannot rely on cues like hair colour or when they see the person again under a different lighting or at a different angle.

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