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Configural face processing develops more slowly than featural face processing

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Abstract. Expertise in face processing takes many years to develop. To determine the contribution of different face-processing skills to this slow development, we altered a single face so as to create sets of faces designed to measure featural, configural, and contour processing. Within each set, faces differed only in the shape of the eyes and mouth (featural set), only in the spacing of the eyes and mouth (spacing set), or only in the shape of the external contour (contour set). We presented adults, and children aged 6, 8, and 10 years, with pairs of upright and inverted faces and instructed them to indicate whether the two faces were the same or different. Adults showed a larger inversion effect for the spacing set than for the featural and external contour sets, confirming that the spacing set taps configural processing. 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, with no significant difference beginning at age 6 on the external contour set and beginning at age 10 on the featural set. Overall, the results indicate that adult expertise in configural processing is especially slow to develop.

1 Introduction

Adults are 'experts' in face processing: they can recognise thousands of individual faces rapidly and accurately, and they can easily decipher specific cues in a single face, including emotional expression, head orientation, direction of gaze, and sound being mouthed (Bahrick et al 1975; see Bruce and Young 1998 for a review). Many face processing skills are present during infancy: newborns are drawn toward face-like patterns over non-face patterns (Goren et al 1975; Johnson et al 1991; Mondloch et al 1999; Valenza et al 1996)—a result which suggests that even newborns are able to detect the first-order relational features of the face (two eyes above a nose, and a mouth below the nose—Diamond and Carey 1986; but see Simion et al 2001 for an alternative explanation). In addition, newborns look longer at faces rated attractive by adults than at faces rated unattractive (Slater et al 1998, 2000), and they can recognise their mother's face if the external features (ie hair) are present (Bushnell et al 1989; Pascalis et al 1995). By 7 months of age, they process the relationship among the parts of a face; after being habituated to two faces, 7-month-old infants treat a composite face consisting of the external portion of one familiar face and the internal parts of the other as if it were a novel face (Cashon and Cohen 2001). This may represent the earliest evidence of holistic processing, which we will define as the 'glueing' together of the features such that information about individual features is less accessible (Carey and Diamond 1994).

Despite the early emergence of some face-processing skills, adultlike expertise in recognising facial identity is not achieved until adolescence: 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 et al 1980). Even in matching tasks, which eliminate memory demands, performance improves dramatically between 4 and 11 years of age (Bruce et al 2000).

Various studies have attempted to identify the nature of children's immaturity in identifying faces. Problems with holistic processing of faces are an unlikely source of this immaturity. Holistic processing has been demonstrated most clearly by studies with chimeric faces in which the top half of one face is aligned with the bottom half of another. When adults are instructed to identify the top half of a composite face, they are impaired, presumably because holistic processing prevents them from attending exclusively to the features in the top half and ignoring the whole Gestalt (Carey and Diamond 1994; Hole 1994; Young et al 1987). Adults' performance improves after manipulations that disrupt holistic processing: misaligning the top and bottom halves or presenting the faces in a noncanonical, inverted orientation. The magnitude of the chimeric face effect is the same in 6-year-old children (the youngest age tested) as it is in adults (Carey and Diamond 1994). So is the magnitude of the part – whole recognition effect that has been taken as evidence for holistic processing in adults (Tanaka and Farah 1993): like adults, 6-year-olds recognise a facial feature better in the context of the whole face in which they learned it than in isolation (Tanaka et al 1998; but see Gauthier et al 1998, and Tanaka and Gauthier 1997 for an alternative interpretation and evidence that the effect is not restricted to faces). Thus, holistic processing appears to be mature by 6 years of age and cannot account for developmental changes in face processing after that age.

Because all faces share the same first-order relational features, recognising facial identity requires processing the shape of individual features (eg eyes, mouth, chin) and/or second-order relations, which refers to the spacing among features (eg distance between the eyes or between the mouth and chin). Identification based on these cues involves featural and configural processing, respectively. Evidence that inversion has a disproportionate effect on adults' recognition of faces relative to other classes of objects (eg Yin 1969) has been taken as evidence that adults rely on configural processing for the identity of upright faces. The strongest evidence that inversion disrupts configural processing comes from a study which tested adults with versions of a single face that differed either in the shape of individual features or the spacing between features (Freire et al 2000). Inverting the faces disrupted adults' ability to discriminate faces in the spacing set, but not faces in the featural set. Similarly, in a recognition task, inversion disrupted adults' ability to correctly identify faces from a study set when the faces differed in the spacing of features, but not when the faces differed only in the characteristics of local features (Leder and Bruce 2000; see also Rhodes et al 1993). Inversion appears to disrupt the perception and encoding of configural information, rather than the retention of configural information—at least over short delays. Freire et al (2000) drew this conclusion from their finding that the inversion effect for the spacing set was of similar magnitude when participants made simultaneous discriminations and when they matched a test stimulus to a target presented up to 10 s earlier. The effect of inversion on the perception and encoding of spatial relations was also demonstrated in a study in which adults rated the bizarreness of faces in which the spacing of features or their properties were distorted. For faces with distorted features, adults rated the faces as quite bizarre regardless of orientation, with a slight but systematic increase as the face was rotated away from upright. In contrast, for faces with distorted spacing, adults rated the faces as quite bizarre when they were upright or slightly rotated, but not when they were inverted (Murray et al 2000).

Several studies suggest that children may rely less on configural processing than do adults. First, under most conditions judgments of facial identity by children aged 6 and 8 years, unlike those of adults, are not impaired by inversion when targets and foils are two different faces (ie when both featural and spacing cues are available) (Carey and 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). Second, children aged 4 – 7 years perform poorly—although better than chance—when asked to detect a target face when it is presented among distractors that differ only in the spacing of features (Freire and Lee 2001); their accuracy is higher when the distractors differ from the target in the shape of individual features. Similarly, 6-year-olds have difficulty matching faces when they differ in point of view, clothing, or lighting (Benton and Van Allen 1973, as cited in Carey et al 1980; Geldart 2000). Such changes render configural processing more important because faces no longer can be matched accurately on the basis of the appearance of individual features. In contrast to these findings, only one study has claimed that configural information is equally important to children and adults. Baenninger (1994) concluded that children aged 6–10 years do engage in configural processing because, like adults, their ability to recognise faces was affected by misplacing facial features (eg putting the mouth above the eyes). However, Baenninger's manipulation disrupted first-order relational features and, consequently, holistic processing—not just second-order relations. Overall the literature suggests that children may perform more poorly than adults on facial-identity tasks because they rely less on configural processing.

Children also differ from adults in the facial characteristics that they attend to when engaged in featural processing. Adults rely more on internal facial features than on external features (eg hair) when recognising familiar faces (Ellis et al 1979). In contrast, children younger than 7 years of age rely more on external features, and it is only when children are between 9 and 11 years of age that they show the adultlike pattern (Campbell and Tuck 1995; Campbell et al 1995). Furthermore, 6-year-olds and 8-year-olds are influenced more by paraphernalia (eg glasses, hats) than are 10-year-olds and adults when matching unfamiliar faces (Carey and Diamond 1977), although the influence is reduced when the faces presented are less similar (Baenninger 1994). Finally, in a recent study, Schwarzer (2000) asked 7-year-olds, 10-year-olds, and adults to sort eight line drawings of faces into two categories (child/adult). When later asked to categorise ambiguous drawings, 7-year-olds did so on the basis of an individual feature (eg eyes) whereas adults did so on the basis of overall similarity (eg the number of features that could be assigned to either category). These results indicate that, when categorising faces, 7-year-olds may attend less to the relationships among features than do adults.

Taken together, these studies suggest that children perform worse than adults on face-perception tasks because they rely more on featural processing and less on configural processing than do adults, and because they are more easily distracted by paraphernalia. Freire and Lee (2001) demonstrated that children aged 4–7 years were better at recognising a face that differed from distractor faces in the shape of individual features than they were at recognising a face that differed from distractors in the spacing among features. However, performance was poor on both tasks, and no study has made a direct comparison of developmental changes in featural versus configural processing of faces in older children. That was the purpose of the current study. On the basis of the technique used by Freire et al (2000), we modified a single female face (called 'Jane') to create eight new versions (called 'sisters')—four that differed in the shape of internal features (featural set) and four that differed in the spacing of internal features (spacing set). To encourage configural processing of the internal features, we had models wear identical caps that covered the hair and ears and used computer software to remove natural facial markings (eg freckles). Pairs of faces were presented sequentially and, for each pair, participants used a joystick to indicate whether the two faces were the same or different. In addition, we included four versions of Jane that differed only in the shape of the external contour (contour set) so that we could compare children's performance when the critical differences were external (contour set) versus internal (spacing and featural sets). A control set of three faces (Jane's cousins) differed from the original Jane in features, spacing, and outer contour, and were used to determine that each participant understood the task.

We presented faces both upright and inverted to verify that our stimuli tap configural (spacing set) versus featural (featural set) processing and to determine the type of processing that is used to discriminate faces in the contour set. Previous research has shown that inversion disrupts configural processing but has little or no effect when stimuli are processed featurally (Collishaw and Hole 2000; Freire et al 2000; Murray et al 2000). On the basis of these findings, we expected the largest inversion effect in adults for the spacing set, a small inversion effect for the featural set, and were unable to make a prediction about the contour set because changing the external contour creates both featural changes (eg chin shape) and spacing changes (eg spacing between the mouth and chin). We tested children aged 6, 8, and 10 years as well as adults in order to trace the development of various face-processing skills. On the basis of previous evidence of the larger influence of external facial features and paraphernalia on young children's perception of faces, we predicted that performance on the featural and contour sets would reach adult levels earlier than performance on the spacing set.

2 Method

2.1 *Participants*

The participants were four groups of thirty-six Caucasian participants: 6-year-olds (±3 months), 8-year-olds (±3 months), 10-year-olds (±3 months), and adults (aged 18–28 years). 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. Adults were undergraduate students participating for credit in a psychology course at McMaster University.

Because one goal of our research is to study the effects of early visual deprivation on various face-processing skills (eg 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, adults, 10-year-olds, and 8-year-olds had Snellen acuity of at least 20/20 in each eye without optical correction, and 6-year-olds had visual acuity of at least 20/25 on the Goodlight Crowding test. In addition, all participants had 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 s of arc on the Titmus test. Because some face-processing skills are lateralised (eg Deruelle and de Schonen 1998), we included only participants who were right-handed, as determined by a handedness test adapted from Peters (1988). An additional fifty-three participants were tested, but excluded from the final analysis: thirty-two failed visual screening (eleven 6-year-olds, nine 8-year-olds, eight 10-year-olds, and four adults), two (6-year-olds) were not right-handed, six failed the practice task (see below), three moved the joystick erratically throughout the procedure (one 8-year-old, two 10-year-olds), and one (a 6-year-old) refused to participate. Seven 6-year-olds and two 10-year-olds were correct on fewer than 70% of the control trials (Jane's cousins). Because such low performance might reflect poor motivation or attention or inability to understand the task, we replaced their data.

2.2 *Stimuli and apparatus*

Gray-scale digitised images of Caucasian female faces were taken with 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 no jewelry or glasses, and a surgical cap covered their hair and ears. Digitised images were downloaded to a Macintosh LC-475 computer, and three sets of face stimuli (spacing, featural, and contour) were created with the graphics software program Adobe Photoshop. On the basis of the technique used by Freire et al (2000), we modified a single face (called 'Jane') to create twelve new versions (called Jane's sisters). The four faces in the spacing set were created by moving the eyes 4 mm (0.23 deg from the testing distance of 100 cm) up, down, closer together, or farther apart, relative to the original, and by moving the mouth 2 mm (0.12 deg from 100 cm) up or down (figure 1, panel A). Pilot testing with adults showed that moving the features more than this eliminated the inversion effect—presumably because participants were able to process the spaces between parts of the face (eg the area between the eyes) as features that varied in size and/or location when the eyes and mouth were moved. According to anthropomorphic norms (Farkas 1981), we moved Jane's eyes up or down by 0.95 SD, her mouth up or down 1.06 SD, and her eyes closer together or farther apart by 2.60 SD. An inability to discriminate these faces would imply an inability to discriminate the majority of faces in the population on the basis of the spacing among features. The four faces in the featural set were created by replacing the model's eyes and mouth with the features of different females. We chose features of the same length to minimise resulting changes in the spacing among features (figure 1, panel B). The four faces in the contour set were created by pasting the internal portion of the original face within the outer contour of four different females (figure 1, panel C). The control stimuli consisted of Jane and three different females—faces that differed from the original Jane in features, spacing, and outer contour. All stimuli were 10.2 cm wide and 15.2 cm high (5.7 deg × 9.1 deg from the testing distance of 100 cm).

The stimuli were presented on a monochrome Radius 21-GS monitor controlled by a Macintosh LC-475 computer and Cedrus Superlab software. Participants signalled their responses via a joystick and the experimenter initiated trials by pressing a key on the keyboard.

2.3 *Procedure*

After the procedures were explained, informed consent was obtained from the adult participants and a parent of the children. In addition, assent was obtained from the 8-year-old and 10-year-old children. The participant sat in a darkened room with his/her eyes 100 cm from the monitor. The procedure began with a practice task that was designed to ensure that all participants understood the instructions and to teach them how to use the joystick to signal whether they saw the two faces presented during each trial as the same or different. During each trial of the practice task, there were either two identical faces or two radically different versions of a face (eg a face with eyes rotated 45° clockwise paired with the same face with the eyes rotated counterclockwise). We presented the first three pairs of faces side-by-side and provided feedback on the participant's response. There were then 12 trials with the pair of faces to-be-compared presented sequentially: the first face appeared for 360 ms and, following an interstimulus interval ranging from 84 to 120 ms, the second face appeared and remained on the screen until the participant made a response. Participants were asked to move the joystick forward if the two faces were the same and towards themselves if the two faces were different. To participate in the main experiment, participants were required to be correct on at least 10 of these 12 trials. Each child was provided with up to three opportunities to meet this criterion; only three 6-year-olds and three 8-year-olds failed to do so.

The experimenter initiated the main experiment by saying: "*Let's try another game that's like the game you just played, OK? This is Jane* (the original model was presented on the screen), *and these are all of Jane's sisters* (the twelve modified versions of Jane were shown). *Jane has many sisters. They all look alike, but they are all different people. They are kind of like twins. Do you know any twins? ... They like to play a game where they mix people up. So, you are going to see one face flash up fast on the screen, and then another face. You have to show me, using the joystick, if you think the faces are the same or different, OK? Try to answer as fast as possible, but try to give the right answer.*" The instructions for the joystick were then repeated and younger children were asked to demonstrate what they should do if they saw the same sister twice and then what they should do if they saw two different sisters.

During each trial, the first (model) face appeared for 200 ms, and, after an interstimulus interval of 300 ms, the second (test) face appeared until the participant signalled a response with a joystick. Pilot testing showed that these values allowed participants of all ages sufficient time to get an initial impression of the face and that they prevented apparent-motion cues from signalling the presentation of a different face.

All participants were tested on 90 upright trials followed by 90 inverted trials. The 90 trials were divided into three 30-trial blocks: spacing, featural, and external contour. Trials were blocked to encourage participants to use specific face-processing strategies. Prior to the three blocks of upright trials and again prior to the three blocks of inverted trials, the participant was given six practice trials—one same and one different trial from each stimulus set. For each participant, the order in which blocks were presented was the same for upright and inverted trials. Three orders were used: spacing – featural – contour, featural – contour – spacing, and contour – spacing – featural. Within each block the correct response was 'same' for half of the trials, each face served as a test face as often as the model face, and each face was presented half of the time on a 'same' trial and half of the time on a 'different' trial. Within a block, all participants saw the same random order of trials. To encourage children to complete the task, we provided stickers at various points. In addition, visual screening and the handedness test were inserted during testing in order to provide the child with breaks.

After the last block of inverted trials, we presented a block of upright trials with Jane and her cousins. This block consisted of 32 trials with either the same face twice (16 trials) or two completely different faces (16 trials). The purpose of this control task was to ensure that participants were still 'playing the game' at the end of the procedure. (The first twelve adults did not receive the control task.) The entire procedure required 45 min (range = 30 min for adults to 60 min for children, including breaks).

2.4 *Data analysis*

For each of the six blocks of trials for each participant, we calculated the proportion of responses that were correct and the median reaction time on correct trials. Preliminary analyses indicated that there were no effects of order and no effects of gender for any age group.

2.4.1 *Accuracy.* To measure age differences in the ability to discriminate faces that differed on all dimensions (Jane's cousins) we conducted an ANOVA on proportion correct responses with age as the between-subjects factor.

To measure age differences in particular face-processing strategies, we conducted an ANOVA on proportion correct responses that had two within-subjects factors (face set and orientation) and one between-subjects factor (age). Because the data showed clear inversion effects for all face sets at all ages (see figure 2), the significant 3-way interaction was explored by conducting separate ANOVAs for upright and inverted trials, in each case with two factors (age, face set). Differences in the rate of development for different face-processing skills would be revealed by a significant age × face set interaction on upright trials.

To validate the origin of the three-way interaction, we calculated a difference score (accuracy on upright trials minus accuracy on inverted trials) for each face set for each age group. If adults rely more on configural processing when discriminating faces in the spacing set than when discriminating faces in the featural set, their difference scores should be larger for the spacing set. If reliance on configural processing increases with age, then difference scores should increase with age on the spacing set more than on the featural set. We were unable to predict the effect of inversion on the external contour set, because the discrimination of these faces may be based on isolated external features, such as chin shape (featural processing), or on the spacing between internal features and the external contour (configural processing). However, comparing the effect of inversion on the external contour set with the effect of inversion on the featural versus spacing sets should provide insight as to the type of processing used to discriminate faces in the external contour set.

2.4.2 *Reaction times.* To determine whether differences in accuracy among face sets could be attributed to speed – accuracy trade-offs, we also conducted a similar ANOVA on median reaction time on correct trials. We explored the age × orientation interaction with analyses of simple effects, with an emphasis on the effect of orientation at each age, because differences between age groups in overall reaction time were not of theoretical interest.

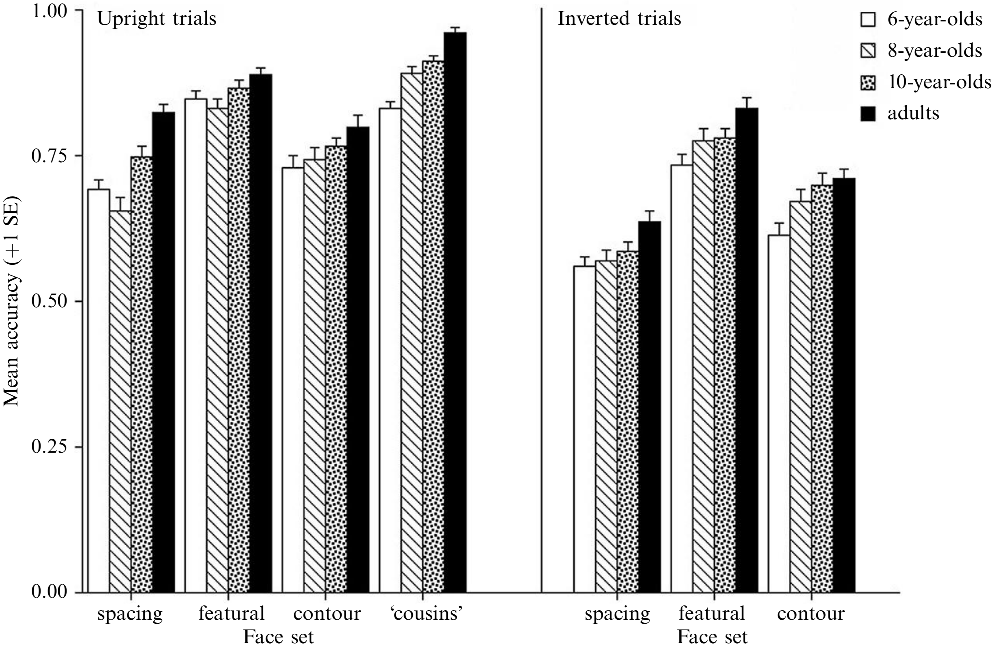

Figure 2. Mean accuracy (+1 SE) for each face set and each age group when stimuli were presented upright (left panel) and inverted (right panel).

3 Results

3.1 *Proportion correct*

The ANOVA on proportion correct on Jane's cousins revealed a significant effect of age ($F_{3,128} = 18.39$, $p < 0.001$). As shown in figure 2, the number of errors decreased monotonically with age. All possible pairwise comparisons were statistically significant (ps < 0.01; Fisher's PLSD), with one exception—10-year-olds were not more accurate than 8-year-olds ($p > 0.10$).

The ANOVA on proportion correct for the three experimental face sets revealed main effects of age ($F_{3,140} = 13.22$, $p < 0.001$), face set ($F_{2,280} = 176.97$, $p < 0.001$), and orientation ($F_{1,140} = 247.33$, $p < 0.001$). The ANOVA also revealed a significant interaction between age and orientation ($F_{3,140} = 2.92$, $p < 0.05$), and between face set and orientation ($F_{2,280} = 13.66$, $p < 0.001$), as well as a 3-way interaction between age, face set, and orientation ($F_{6,280} = 2.46$, $p < 0.05$). To analyse the 3-way interaction, we conducted separate ANOVAs for the upright and inverted conditions.

3.1.1 *Accuracy on upright trials.* The ANOVA for upright trials revealed main effects of age ($F_{3,140} = 12.10$, $p < 0.001$) and face set ($F_{2,280} = 81.23$, $p < 0.001$), and a significant age × face set interaction ($F_{6,280} = 3.46$, $p < 0.01$). As shown in figure 2, the magnitude of age differences in accuracy varied across face sets, with the largest differences occurring for the spacing set. Analysis of simple effects showed a significant effect of age for the featural set ($F_{3,140} = 3.14$, $p < 0.05$) and the spacing set ($F_{3,140} = 16.15$, $p < 0.001$), but the effect of age for the external contour set only approached significance ($F_{3,140} = 2.49$, $p = 0.06$). Dunnett's t-test showed that for the featural set 6-year-olds ($p < 0.05$) and 8-year-olds ($p < 0.01$) made more errors than adults, but 10-year-olds did not ($p > 0.05$). On the spacing set all groups of children, including 10-year-olds, made more errors than adults (all ps < 0.01).

3.1.2 *Accuracy on inverted trials.* As shown in figure 2, performance on inverted trials varied across face sets, but was more similar across age groups than performance on upright trials. The ANOVA for inverted trials revealed main effects of age ($F_{3,140} = 8.77$, $p < 0.001$) and face set ($F_{2,280} = 149.18$, $p < 0.001$), but no significant age × face set interaction ($p > 0.10$). Collapsed across groups, accuracy was higher on the featural set ($M = 0.778$, $SE = 0.009$) than on the external contour set ($M = 0.673$, $SE = 0.010$), as was true for upright trials, and higher on both of these sets than the spacing set ($M = 0.587$, $SE = 0.009$; Fisher's PLSD, all ps < 0.01). Dunnett's t-test showed that on inverted trials 10-year-olds and 8-year-olds were as accurate as adults (ps > 0.05), but that 6-year-olds made more errors than adults ($p < 0.01$). Thus, inverting the face stimuli reduced age differences and eliminated the interaction between face set and age.

3.1.3 *Inversion effect.* For the upright face sets, accuracy on the external contour set was adultlike by 6 years of age, accuracy on the featural set was adultlike by 10 years of age, but even 10-year-olds made more errors than adults on the spacing set. To determine whether these differences reflect different rates of development for featural versus configural processing, we measured the size of the inversion effect for each face set for each age group. As a metric for the inversion effect, we calculated the difference in accuracy between upright and inverted test trials for each participant. Figure 4 shows that inverting the faces reduced accuracy for all face sets for all age groups, and that the size of the inversion effect increased with age on the spacing set, but not on the featural and external contour sets. The 2-way ANOVA (face set × age) showed significant main effects for age ($F_{3,140} = 2.92$, $p < 0.05$) and face set ($F_{2,280} = 13.67$, $p < 0.001$), and a significant age × face set interaction ($F_{6,280} = 2.47$, $p < 0.05$). Analyses of simple effects showed a significant effect of face set for adults ($F_{2,70} = 13.93$, $p < 0.001$) and 10-year-olds ($F_{2,70} = 7.41$, $p < 0.001$), both of whom showed a larger inversion effect on the spacing set than either the featural set or the external contour set (all ps < 0.001, Fisher's PLSD), which did not differ from each other (all ps > 0.10, Fisher's PLSD). In contrast, the size of the inversion effect did not differ across face sets either for 6-year-olds or for 8-year-olds (ps > 0.10). Thus, although 10-year-olds made more errors than adults on the spacing set, they showed a pattern of inversion effects that is similar to that of adults.

3.2 *Median reaction times*

The ANOVA of median reaction times on Jane's cousins revealed a significant effect of age ($F_{3,128} = 39.42$, $p < 0.001$). As shown in figure 3, reaction time decreased monotonically with age; a posteriori tests revealed that all pairwise comparisons were significantly different (all ps < 0.001, Fisher's PLSD).

The ANOVA of median reaction times for the three experimental face sets revealed main effects of both age ($F_{3,140} = 55.99$, $p < 0.001$) and face set ($F_{2,280} = 6.20$, $p < 0.01$). As shown in figure 3, reaction times decreased with age. Reaction times were slower on the external contour set ($M = 1386$ ms) than they were on either the featural set ($M = 1332$ ms) or the spacing set ($M = 1346$ ms) (ps $= 0.01$; Fisher's PLSD). In addition, there was an age × orientation interaction ($F_{3,140} = 2.81$, $p < 0.05$). Because main effects of age are not of theoretical interest, we focused on the effects of orientation for each age group in the analyses of simple effects. There was a main effect of orientation for 8-year-olds ($F_{1,35} = 5.44$, $p < 0.05$) and for adults ($F_{1,35} = 8.21$, $p < 0.001$); both groups had longer reaction times on inverted trials than on upright trials. Reaction times did not vary with orientation for either 6-year-olds or 10-year-olds (ps > 0.1). These data show that the increased errors seen when the faces were inverted cannot be attributed to speed – accuracy trade-offs.

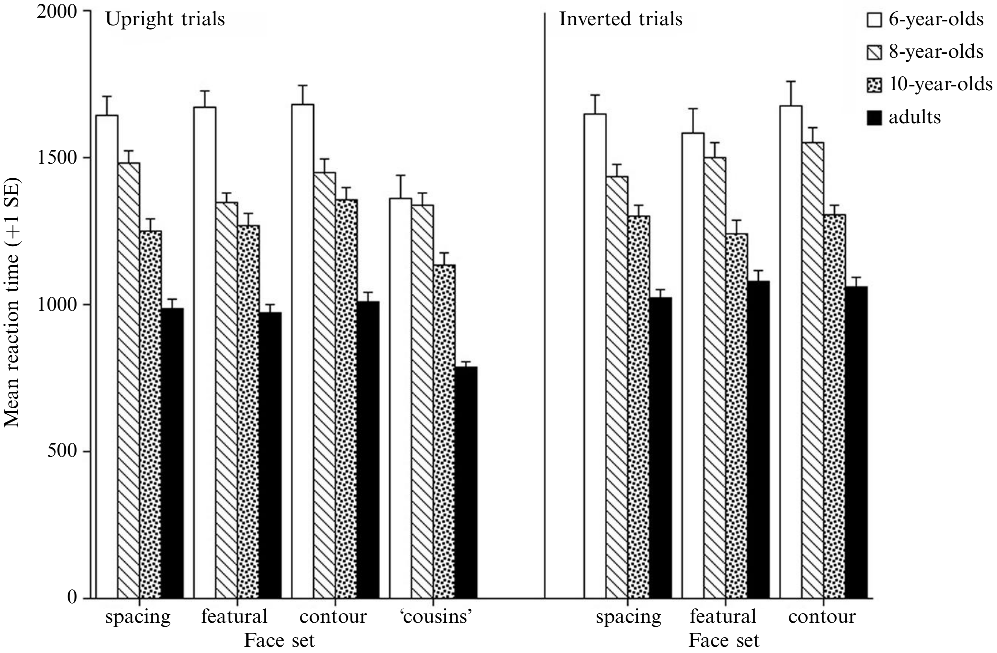

Figure 3. Mean reaction times (+1 SE) on correct trials for each face set and each age group when stimuli were presented upright (left panel) and inverted (right panel).

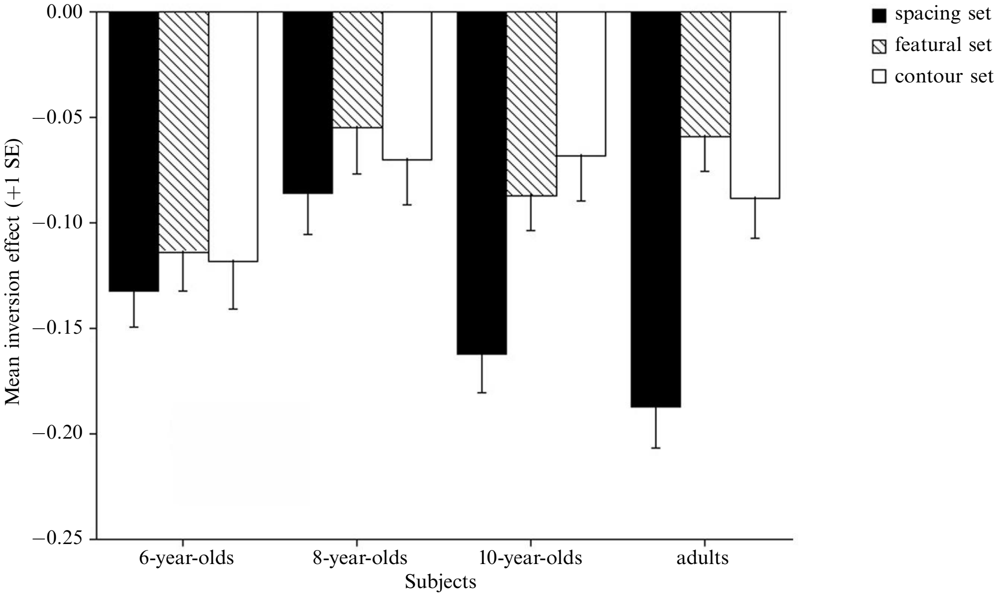

Figure 4. Mean difference scores [accuracy on inverted trials minus accuracy on upright trials (+1 SE)] for each face set and each age group.

4 Discussion

4.1 *Validation of the stimuli*

The results indicate that we were successful in creating a procedure that is differentially sensitive to featural versus configural processing. Adults showed a larger inversion effect for the spacing set than they did for either the featural set or the external contour set, consistent with our hypothesis that the spacing set primarily taps configural processing when upright (Freire et al 2000; Yin 1969): when the faces were inverted, adults' accuracy dropped almost 20% for the spacing set but only about 10% for the featural and external contour sets. This was true despite the fact that accuracy was not limited by floor or ceiling effects for any of the upright face sets, and for two of them (spacing and external contour) accuracy was equivalent when upright. The greater inversion effect for the spacing set also cannot be attributed to a speed–accuracy trade-off since no age group responded more quickly when the faces were inverted. Rather, the pattern of inversion suggests that, as predicted (cf Freire et al 2000), adults were more likely to use configural processing when presented with the spacing set than when presented with the featural and external contour sets.

Unlike previous studies (Freire et al 2000; Leder and Bruce 2000) which reported no inversion effect for face stimuli that differed only in the shape of individual features, we observed a small inversion effect for both the featural and external contour sets. This is likely due to procedural differences. Freire et al (2000, experiments 1 and 2) presented pairs of faces simultaneously and stimuli remained on the screen until a response was made; Freire et al (2000, experiments 3 and 4) presented the target face for 5 s and then presented it paired with a distractor face until a response was made; Leder and Bruce (2000) presented test faces individually, but participants had learned the faces during a training phase, and faces remained on the screen until identified. In contrast, in order to reduce the opportunity to parse and analyse individual facial features and to encourage configural processing, our faces were presented sequentially and the first face remained on the screen for only 200 ms. Our procedure may have introduced a baseline inversion effect for all face sets, similar to that reported previously for other mono-oriented stimuli, including houses and airplanes (Diamond and Carey 1986; Yin 1969). In addition, changing the shape of any facial feature produces small changes in spacing, and may cause a small inversion effect for that reason (see also Murray et al 2000). For example, a new external contour not only changes the shape of an individual external feature (eg chin shape), but also the spacing between internal features (eg the mouth) and the external contour. Similarly, a new mouth shape introduces changes in the distance from the bottom of the mouth to the chin.

4.1 *Developmental changes*

Our results are consistent with previous studies showing that face processing skills improve between 6 and 10 years of age but are not adultlike until after the age of 10 years (Benton and Van Allen 1973, as cited in Carey et al 1980; Bruce et al 2000; Carey et al 1980; Carey and Diamond 1994). On the control task involving the discrimination of entirely different faces, accuracy increased from 83% correct in 6-year-olds to 91% correct in 10-year-olds, whose accuracy was lower than the 96% correct achieved by adults. Although such age differences may reflect developmental changes in attention, memory, or other non-perceptual factors, the differential performance across face sets indicates that they also reflect the development of specific face-processing skills.

Our results provide evidence of configural processing in 6-year-olds: their accuracy on the spacing set was above chance when the faces were upright. This finding is consistent with previous research showing some evidence of configural processing in young children (Brace et al 2001; Carey and Diamond 1994; Freire and Lee 2001), and perhaps even newborns, whose preference for attractive faces is based on internal features and is disrupted when faces are inverted (Slater et al 2000). Nevertheless, our data show that the development of configural processing lags behind the development of featural processing and of processing based on the external contour. With upright faces, 6-year-olds (the youngest age) were nearly as accurate as adults for the external contour and featural sets (see figure 1), with no significant difference for the former and only a small difference in means for the latter. In contrast, even 10-year-olds made significantly more errors than adults on the spacing set. Furthermore, adults and 10-year-olds showed a larger inversion effect on the spacing set than they did on the featural and external contour sets—presumably because configural processing of faces is compromised when stimuli are inverted. The size of the inversion effect did not vary between face sets for 6-year-olds and 8-year-olds, a result indicating that they were less able to take advantage of configural information in the upright spacing set.

Children's poor performance on the upright spacing set, relative to adults, cannot be attributed to faces in the spacing set being more difficult to discriminate in general. Adults' accuracy did not differ for the upright external contour and spacing sets and was not limited by floor or ceiling effects. Nevertheless, 6-year-olds were as accurate as adults on the upright external contour set, but even 10-year-olds made more errors than adults on the upright spacing set. Moreover, examination of figure 2 and the results of the ANOVA indicate that when the stimuli were presented under conditions that do not favour configural processing (ie inverted), performance improved with age by similar amounts for all three face sets. In other words, our results are consistent with the idea that slow development of expertise in face processing (eg Carey et al 1980) is due to the slow development of configural processing.

Our face stimuli were all variations of a single female model, and so it is possible that the same developmental pattern would be not be observed with a different set of faces—particularly male faces or female faces with less variability in features. We note, however, that the variations in the spacing set on which children performed poorly covered most of the range of natural variation (see section 2.2) and children did as poorly on this set when it was presented first as when it followed the possibly more salient featural variations. Moreover, our results are consistent with previous studies in which the stimuli were derived from a single male model (Freire et al 2000; Freire and Lee 2001). In summary, it is likely that the developmental pattern we observed is generalisable across adult faces, although future studies in which variations of several model faces are created would help to verify this.

Configural processing may approach adultlike levels only after 10 years of age because it takes more than 10 years of experience to become a face 'expert' (Carey and Diamond 1994). The role of configural processing in expertise has been demonstrated in adults who are experts with a category of non-face objects, the members of which share first-order relations. Diamond and Carey (1986) report an inversion effect comparable to that seen for faces when dog experts are shown upright and inverted dogs—but only if the experts are shown the breed of dog with which they have expertise. Likewise, Gauthier et al (2000) found that pictures of cars and birds activate the fusiform face area, a cortical area highly responsive to faces, when shown to car and bird experts, respectively. Although expertise may take years to develop under normal conditions, adults can be trained to process a novel set of stimuli configurally within a short time. Gauthier and Tarr (1997) trained adults to recognise 30 'greebles' at the individual, gender, and family levels. When later tested on their ability to recognise parts of a new set of greebles, 'experts', but not novices, were more accurate when stimuli were presented in the studied point of view—but only when the stimuli were upright. In a subsequent study Gauthier et al (1999) found that greeble experts recruit the fusiform gyrus 'face area' when matching upright greebles, but not when matching inverted greebles. These results suggest that the normally slow development of expertise in configural processing of upright faces might be accelerated by specific training.

Regardless of the reason for children's poor configural processing, our data show that children's relatively poor performance in identifying faces (Bruce et al 2000; Carey et al 1980) is due largely to poor configural processing, an ability that develops more slowly than the processing of individual features or the shape of the external contour.

The slow development of configural processing is particularly interesting because it is this aspect of face processing that is most dependent on early visual input. Individuals who were deprived of early visual input during the first 2 to 6 months of life by dense, central cataracts that blocked all patterned input to the retina perform normally on the featural and external contour sets, but show deficits on the spacing set (Le Grand et al 2001 and unpublished data). Apparently, early visual input is necessary to set up the neural architecture that will become specialised for configural processing—a specialisation that we now know takes more than 10 years to become adultlike.

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