Research Article

Impairment in Holistic Face Processing Following Early Visual Deprivation

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ABSTRACT—*Unlike most objects, faces are processed holistically: They are processed as a whole rather than as a collection of independent features. We examined the role of early visual experience in the development of this type of processing of faces by using the composite-face task, a measure of holistic processing, to test patients deprived of visual experience during infancy. Visually normal control subjects showed the expected composite-face effect: They had difficulty perceiving that the top halves of two faces were the same when the top halves were aligned with different bottom halves. Performance improved when holistic processing was disrupted by misaligning the top and bottom halves. Deprived patients, in contrast, showed no evidence of holistic processing, and in fact performed significantly better than control subjects when top and bottom halves were aligned. These findings suggest that early visual experience is necessary to set up or maintain the neural substrate that leads to holistic processing of faces.*

Adults are experts at processing faces: They can recognize thousands of individual faces and can quickly decode emotional expression and direction of gaze. Except with special training (e.g., car dealers identifying cars), adults do not demonstrate the same expertise with any other stimulus category. Unlike other objects, faces tend to elicit holistic processing (Tanaka & Farah, 1993): Their parts are integrated into a whole or Gestalt-like representation, thereby reducing the accessibility of information about individual features (for a review, see Maurer, Le Grand, & Mondloch, 2002). A compelling demonstration of holistic processing is the *composite-face effect* (Carey & Diamond, 1994; Hole, 1994; Hole, George, & Dunsmore, 1999; Young, Hellawell, & Hay, 1987). Adults find it difficult to recognize the top half of a celebrity's face when it has been aligned with the bottom half of a different face (Young et al., 1987). Presumably, holistic processing binds the two halves of the face and creates a novel face, thereby making it difficult to recognize the person in the top half. Adults perform better on this task if holistic processing is disrupted, for example, by misaligning the two halves or inverting the face (Young et al., 1987). The composite-face effect also occurs for same/different judgments about the top halves of unfamiliar faces (Hole, 1994; see Fig. 1). In addition, adults recognize the features from an individual's face more easily in the context of the whole face (e.g., Larry's nose in Larry's face) than in isolation (*the whole/part advantage*; Tanaka & Farah, 1993). These findings demonstrate that facial features are not represented individually, but rather are integrated into a holistic representation.

In this article, we examine the role of early visual experience in setting up the neural substrate for holistic processing of faces. Newborns look longer at stimuli with facelike structure than at stimuli with the features arranged in a nonfacelike manner (e.g., Johnson, Dziurawiec, Ellis, & Morton, 1991; Mondloch et al., 1999; but there are alternative explanations—e.g., Simion, Macchi Cassia, Turati, & Valenza, 2001). Within a few days of birth, they recognize their mothers' faces (e.g., Bushnell, 2001; Pascalis, de Schonen, Morton, Deruelle, & Fabre-Grenet, 1995) and look longer at faces rated attractive by adults than at faces rated unattractive (e.g., Slater et al., 1998). By 3 months, infants show evidence of integrating facial features into a whole, rather than perceiving them as a collection of independent elements (Cashon & Cohen, 2003).

The presence of face-processing abilities in young infants has led some theorists to argue that there is an innately specified face module (e.g., Slater & Quinn, 2001). Compelling evidence

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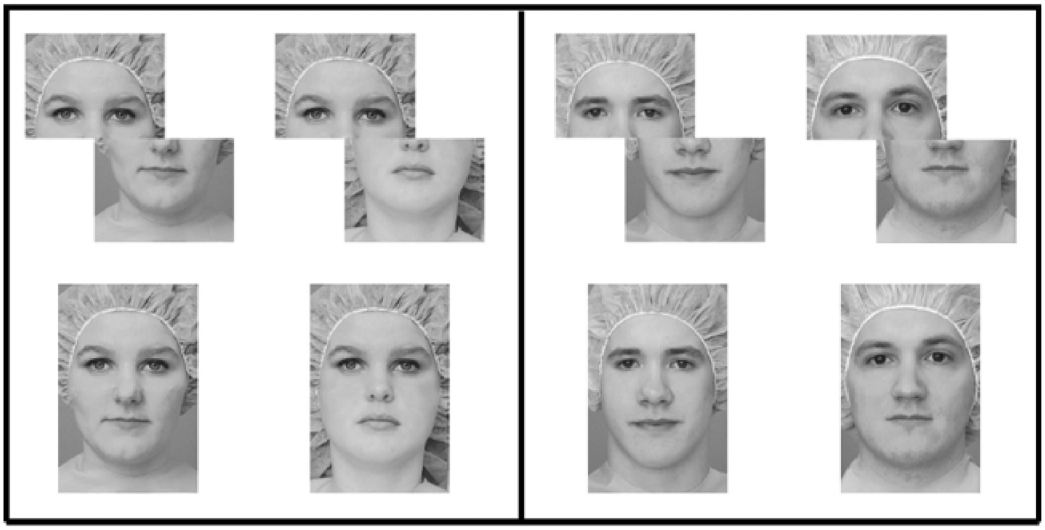

Fig. 1. Composite-face stimuli. Two face pairs from the misaligned condition are in the top row, and two face pairs from the aligned condition are in the bottom row. In each face pair, the top halves are either identical (examples in left panel) or different (examples in right panel). For all face pairs, the bottom halves are different. In the aligned condition, holistic processing creates the impression that the top halves are always different.

for this view comes from the case of Adam, who at 1 day of age sustained brain damage that resulted in a profound impairment in face recognition (prosopagnosia; Farah, Rabinowitz, Quinn, & Liu, 2000). Other theorists argue that exposure to faces during early infancy recruits the cortical networks that will become specialized for face processing (e.g., de Schonen & Mathivet, 1989; Morton & Johnson, 1991; Nelson, 2001). Morton and Johnson (1991) argued that a primitive subcortical mechanism, *conspec*, draws newborns toward faces and has the effect of feeding training signals to the developing cortex. In support of such theories, we have reported abnormalities in some aspects of face processing in patients who were deprived of early visual experience by dense congenital cataracts (Geldart, Mondloch, Maurer, de Schonen, & Brent, 2002; Le Grand, Mondloch, Maurer, & Brent, 2001a, 2001b, 2003; Mondloch, Le Grand, & Maurer, 2003). Despite years of compensatory visual input following treatment for the initial deprivation, the patients show permanent deficits in distinguishing faces that differ only in the spacing among features (Le Grand et al., 2001a, 2001b, 2003) and in matching faces' identity when the matching face is presented from a novel point of view (Geldart et al., 2002)—tasks that require sensitivity to the spatial relations among facial features (second-order relations; Mondloch, Geldart, Maurer, & Le Grand, 2003). Early visual deprivation has no apparent effect on the later development of processing based on individual facial features (featural processing), as shown by normal ability to distinguish faces that differ only in the shape of individual features (Le Grand et al., 2001a, 2001b) and to match faces on the basis of emotional expression, vowel being mouthed, or direction of eye gaze (Geldart et al., 2002).

In the present study, we evaluated the role of early visual experience in the development of holistic face processing by comparing the size of the composite-face effect in individuals treated for bilateral congenital cataracts and individuals with a normal visual history.

EXPERIMENT 1: THE COMPOSITE-FACE EFFECT—A MEASURE OF HOLISTIC PROCESSING

The purpose of Experiment 1 was to test our version of the composite-face task in visually normal adults to evaluate its appropriateness for testing patients. We wanted to create a highly robust composite-face effect that was not influenced by ceiling or floor effects. We predicted that matching the identical top halves of two faces when they were aligned with different bottom halves would be particularly difficult because holistic processing would "bind" the top and bottom halves and thereby create the impression that the two top halves were different. Matching the same top halves when they were misaligned with the bottom halves was expected to be less difficult, as misaligning the faces would disrupt holistic processing.

Method

Participants

Twenty-four (12 female; mean age = 20 years, range: 18–22 years) undergraduate students at McMaster University, Canada, participated in the experiment for course credit. All participants were Caucasian and right-handed, and passed a screening exam for normal vision (Mondloch, Le Grand, & Maurer, 2002). Three additional participants were excluded because they failed the visual screening.

Apparatus

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 trials by pressing a key on the keyboard, and participants signaled their responses via a joystick.

Stimuli

Face composites were created from gray-scale digitized images of adult Caucasian faces. Models wore no jewelry, glasses, or makeup, and a surgical cap covered their hair and ears. Using Adobe Photoshop, we created composites by splitting face images in half horizontally across the middle of the nose, and then recombining the faces using the top and bottom halves of different individuals. In the *aligned* condition, the top and bottom face segments were properly aligned. In the *misaligned* condition, the top half of each face was misaligned by shifting it horizontally to the left by half a face width (see Fig. 1). The same face composites were used in both conditions, and the location of the top half of each face was constant. Stimuli in the aligned condition were 9.8 cm wide and 14 cm high (5.6° × 8° of visual angle from a distance of 100 cm). Stimuli in the misaligned condition were 14.7 cm wide and 14 cm high (8.4° × 8° from a distance of 100 cm).

Design and Procedure

This study was approved by the research ethics board of McMaster University. Informed written consent was obtained from all participants prior to testing.

Participants sat in a dimly lit room 100 cm from the computer monitor. On each trial, a composite face appeared for 200 ms, and following a 300-ms interstimulus interval, a second composite face appeared for 200 ms. Participants were asked to move a joystick forward if the top halves of the two faces were the same and back if the top halves were different. They were asked to respond as quickly and accurately as possible. The two conditions (misaligned faces and aligned faces) were blocked, with half the participants receiving the misaligned condition first. Within each block, half of the trials ($n = 24$) consisted of face pairs that shared the identical top halves (*same* trials), and half of the trials consisted of face pairs with different top halves (*different* trials). On every trial, the bottom halves of the faces were different. *Same* and *different* trials were intermixed randomly within each block. Prior to each block, participants received 4 practice trials without feedback. Percentage correct and median reaction times for correct trials were recorded.

Results

Analyses

For both accuracy and reaction time, we conducted an analysis of variance (ANOVA) with one between-subjects factor (order: aligned first, misaligned first) and two within-subjects factors (condition: aligned, misaligned; correct response: same, different). To explore significant two-way interactions, we conducted separate ANOVAs for the two types of correct response.

Accuracy

Alignment affected accuracy only on *same* trials (see Fig. 2a). Adults were much less accurate on *same*, aligned trials ($M = 63\%$) than on *same*, misaligned trials ($M = 86\%$). The ANOVA revealed significant main effects for condition, $F(1, 22) = 23.76$, $p < .001$, $\eta_p^2 = .52$, and correct response, $F(1, 22) = 17.84$, $p < .001$, $\eta_p^2 = .49$, but no main effect of order ($p > .1$). There was also a significant two-way interaction between condition and correct response, $F(1, 22) = 24.53$, $p < .001$, $\eta_p^2 = .53$. All other interactions were not significant (all ps $> .1$). The analyses of simple effects revealed a significant effect of condition for *same* trials, $F(1, 23) = 26.98$, $p < .001$, $\eta_p^2 = .54$, but not for *different* trials ($p > .1$).

Reaction Time

As shown in Figure 2d, alignment affected reaction time only on *same* trials. Adults took longer to respond on *same*, aligned trials ($M = 815$ ms) than on *same*, misaligned trials ($M = 621$ ms). The ANOVA revealed a significant effect for condition, $F(1, 22) = 19.83$, $p < .001$, $\eta_p^2 = .47$, and a significant interaction between condition and correct response, $F(1, 22) = 18.35$, $p < .001$, $\eta_p^2 = .45$. All other effects were not significant (all ps $> .1$). The analyses of simple effects showed a significant effect of condition for *same* trials, $F(1, 23) = 28.21$, $p < .001$, $\eta_p^2 = .55$, but not for *different* trials ($p > .1$).

Discussion

These results demonstrate a strong composite-face effect. In the aligned condition, processing the images holistically created the impression that the top halves were always different, despite the fact that on half the trials the two top halves were identical and only the bottom halves differed. When holistic processing was disrupted by misaligning the face halves, accuracy on *same* trials increased by 23%, and reaction time decreased by 194 ms. Adults' accuracy was not affected by ceiling or floor levels in any condition (see Fig. 2a). This finding of a robust composite-face effect demonstrates that the task is a sensitive measure of holistic face processing.

EXPERIMENT 2: THE ROLE OF EARLY VISUAL EXPERIENCE IN HOLISTIC FACE PROCESSING

In Experiment 2, we evaluated the influence of early visual experience on the development of holistic face processing. To do so, we compared the size of the composite-face effect in visually normal control subjects and in patients who had been deprived of patterned vision during infancy and then had many years of delayed visual experience after treatment.

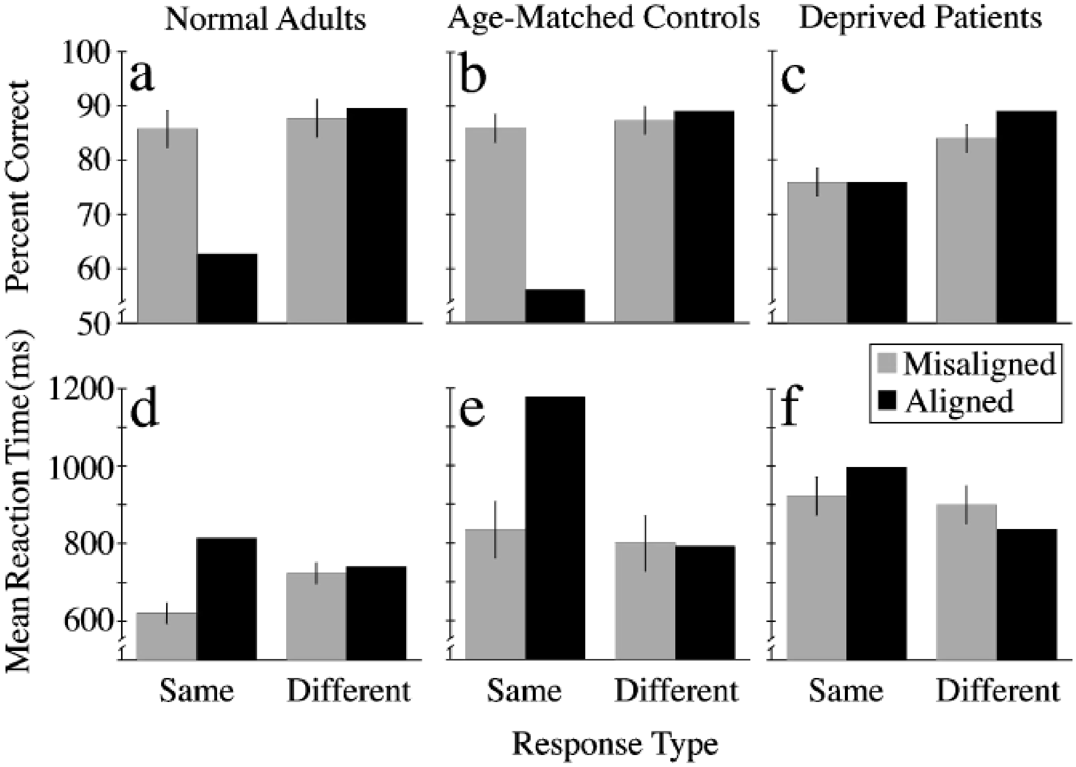

Fig. 2. Mean accuracy scores (top row) and mean reaction times (bottom row) of visually normal adults (a, d), visually normal control subjects (b, e), and deprived patients (c, f) on the composite-face task. Because the study used a within-subjects design (and thus the variance within conditions is irrelevant), the standard error bars represent intrasubject variability between conditions (see Loftus & Masson, 1994).

Method

Participants

The deprived group consisted of 12 right-handed Caucasian patients treated for bilateral congenital cataracts (8 male; mean age at test = 15 years, range: 9–23 years). On their first eye exam, which was always before 6 months of age, all patients were diagnosed with dense central cataracts in both eyes that blocked all patterned input (see Ellemberg, Lewis, Maurer, Lui, & Brent, 1999, for detailed criteria). Duration of deprivation was defined as the period extending from birth until the age of first optical correction following surgery to remove the cataract (i.e., the first time the infant received focused visual input onto the retina) and ranged from 3.2 months to 6.2 months ($M = 4.6$ months). Visual input from this point on was only nearly normal, because the contact lenses focused input perfectly for only one distance, and the eyes could not accommodate for other distances. Patients were tested later in life (at least 8 years after treatment) so they would have ample experience with faces and to allow them time for potential recovery from the initial visual deprivation. At test, visual acuity in the better eye ranged from 20/32 to 20/63 (*Mdn* = 20/50). When necessary, the patient wore an additional optical correction at testing so that the eyes were focused at the testing distance. In a previous study, the deprived patients were found to have relatively normal contrast sensitivity at low and medium spatial frequencies (up to 2 cycles/deg), but considerably reduced spatial contrast sensitivity at high frequencies (Ellemberg et al., 1999).

The deprived group was compared with a visually normal control group comprising 12 participants who were matched individually to the patient group on handedness, gender, race, and age, and who were tested under the same conditions. All the control participants passed a screening exam for normal vision (Mondloch et al., 2002). One additional participant was excluded because he failed the visual screening.

Procedure

This study was approved by the research ethics boards of McMaster University and The Hospital for Sick Children. Prior to testing, the procedures were explained, and informed written consent was obtained from the participant or, in the case of children, from a parent. Children's assent was also obtained.

All participants were tested binocularly using the same procedure described for Experiment 1. Because performance was not affected by order of condition in Experiment 1, all participants in Experiment 2 received the misaligned condition first. This order ruled out the possibility that the composite-face effect was the result of trials from the most difficult condition (*same*, aligned) being presented first. Furthermore, the results of

Experiment 1 showed that even though participants successfully ignored the bottom halves of the faces in the initial misaligned condition, they nevertheless performed poorly on the subsequent *same*, aligned trials.

Results

Analyses

For both accuracy and reaction time, we conducted an ANOVA with one between-subjects factor (group: deprived, control) and two within-subjects factors (condition: aligned, misaligned; correct response: same, different). To explore the significant three-way interaction, we conducted separate ANOVAs for the two groups; significant interactions between condition and correct response for any group were investigated with analyses of simple effects that analyzed the effect of condition for each type of correct response.

Accuracy

Unlike the control group, deprived patients did not benefit from misalignment on *same* trials. They were equally accurate on *same*, aligned trials ($M = 76\%$) and on *same*, misaligned trials ($M = 76\%$). The deprived group actually performed better than the control group ($M = 56\%$) on *same* trials when the faces were aligned (see Figs. 2b and 2c).

The ANOVA revealed main effects for condition, $F(1, 22) = 23.24$, $p < .001$, $\eta_p^2 = .51$, and correct response, $F(1, 22) = 17.02$, $p < .001$, $\eta_p^2 = .43$. The ANOVA also revealed significant interactions between group and condition, $F(1, 22) = 38.70$, $p < .01$, $\eta_p^2 = .64$, and between condition and correct response, $F(1, 22) = 35.65$, $p < .001$, $\eta_p^2 = .61$, as well as a three-way interaction among group, condition, and correct response, $F(1, 22) = 18.34$, $p < .001$, $\eta_p^2 = .45$.

Control Group. The control group was affected by alignment. They performed significantly worse on *same*, aligned trials ($M = 56\%$) than on *same*, misaligned trials ($M = 86\%$) (see Fig. 2b). The ANOVA for the control group revealed main effects for condition, $F(1, 11) = 35.48$, $p < .01$, $\eta_p^2 = .76$, and correct response, $F(1, 11) = 8.83$, $p < .01$, $\eta_p^2 = .45$, as well as a significant interaction for condition and correct response, $F(1, 11) = 41.34$, $p < .01$, $\eta_p^2 = .79$. The analyses of simple effects revealed a significant effect of condition for *same* trials, $F(1, 11) = 53.13$, $p < .001$, $\eta_p^2 = .83$, but not for *different* trials ($p > .1$).

Deprived Group. The ANOVA for the deprived group revealed a significant main effect for correct response, $F(1, 11) = 9.68$, $p < .01$, $\eta_p^2 = .46$. Deprived patients were more accurate on *different* trials than on *same* trials. However, this pattern did not vary with alignment (see Fig. 2c).

Size of the Composite-Face Effect. To directly compare the size of the composite-face effect between the deprived and control groups, we calculated a difference score for each participant (*same*, misaligned trials minus *same*, aligned trials). A planned comparison showed that the size of the composite-face effect was significantly larger in the control group ($M = 30\%$) than in the deprived group ($M = 0\%$), $t(1, 22) = 6.80$, $p < .001$, Cohen's $d = 2.77$. (A Cohen's d of 0.8 or greater is considered to be a large effect size; Cohen, 1988.) The composite-face effect was absent for all deprived patients—even the patient with the shortest duration of deprivation. The size of the composite-face effect in the deprived group was not correlated with age at test or acuity in the better eye ($ps > .1$).

Reaction Time

Reaction times of both groups were longer on *same* trials when the stimuli were aligned than when stimuli were misaligned (see Figs. 2e and 2f). The ANOVA for reaction time showed a significant main effect for correct response, $F(1, 22) = 6.42$, $p < .05$, $\eta_p^2 = .23$, and a significant interaction between condition and correct response, $F(1, 22) = 14.99$, $p < .001$, $\eta_p^2 = .41$. However, there was no effect of group (all $ps > .1$). The analyses of simple effects showed that reaction times were significantly slower when faces were aligned than when faces were misaligned on *same* trials, $F(1, 22) = 8.74$, $p < .01$, $\eta_p^2 = .28$, but not *different* trials ($p > .1$).

A planned comparison showed that the size of the composite-face effect (as measured by the difference in reaction time between *same*, misaligned and *same*, aligned trials) was significantly larger in the control group ($M = -341$ ms) than in the deprived group ($M = -75$ ms), $t(1, 22) = 2.04$, $p < .05$, Cohen's $d = 0.82$. The size of the composite-face effect did not correlate with the patients' age or acuity ($ps > .1$).

Discussion

The results of Experiment 2 indicate that early visual deprivation impairs the development of holistic face processing. As expected, the control group showed a strong composite-face effect. On *same* trials, disrupting holistic processing by misaligning the face halves led to a 30% increase in accuracy and a 341-ms decrease in reaction time. In contrast, the deprived group showed little evidence of a composite-face effect (no change in accuracy and only a 75-ms decrease in reaction time). Indeed, the deprived group performed significantly better than the control group in the critical *same*, aligned trials (see Fig. 2; $p < .01$, Cohen's $d = 1.34$). This result is particularly striking: The deprived patients' impairment in holistic processing is demonstrated here by *enhanced* performance relative to the control group. The deficits in holistic processing were not correlated with visual acuity and cannot be explained on the basis of a general loss in sensitivity to information carried by low spatial frequencies, because contrast sensitivity in this cohort is normal at low spatial frequencies (Ellemberg et al., 1999). Presumably, patients deprived of early visual input fail to integrate facial features into a Gestalt. As a result, they can accurately make same/different judgments for the top halves of faces irrespective of whether the top and bottom halves are aligned or misaligned.[1]

GENERAL DISCUSSION

The results indicate that early visual experience is necessary for the development of normal holistic face processing. Patients deprived of patterned vision for as little as the first 3 months of early infancy fail to demonstrate the normal composite-face effect, an index of holistic processing. Although holistic processing normally aids in face recognition, it is disadvantageous in the experimental situation tested here: judging whether two faces that have different bottom halves share the same top halves when the top and bottom halves are aligned. Under such conditions, patients deprived of early visual experience show supernormal abilities: They are 20% more accurate and 175 ms faster than control subjects in seeing that the top halves are identical. This result, along with the failure of the deprived patients to demonstrate a composite-face effect, indicates that they fail to process faces in a holistic manner. Their impairment in holistic face processing may be caused by early visual deprivation per se, or perhaps more specifically by a lack of experience with human faces during early infancy. In any event, our results demonstrate that the holistic nature of face processing, which distinguishes face from object processing (reviewed in Maurer et al., 2002), is not prespecified, but rather depends on early visual input for its normal development (or at least, for its maintenance).

Our previous research has shown that early visual deprivation prevents the later development of the ability to recognize faces on the basis of the spacing of facial features (second-order relations), but not the ability to process individual facial features (featural processing; Geldart et al., 2002; Le Grand et al., 2001a, 2001b, 2003). It is possible that the impairment in holistic face processing, which prevents the proper integration of facial features, leads to the failure to perceive the spatial relations among the features accurately. That is, holistic processing may be a prerequisite for normal processing of second-order relations. This possibility is consistent with evidence that holistic processing becomes adultlike by 6 years of age (Carey & Diamond, 1994; Joseph & Tanaka, 2003; Mondloch, Pathman, Le Grand, & Maurer, 2003; Tanaka, Kay, Grinnel, Stansfield, & Szechter, 1998), much earlier than sensitivity to second-order relations (Mondloch et al., 2002).

Relative to most common objects, faces are processed in a more holistic manner (Tanaka & Farah, 1993). However, expertise with nonface objects may also engage holistic processing. Adults who have extensive training at recognizing a class of homogeneous nonface objects (Greebles) at the individual level show evidence of holistic processing on the composite task (Gauthier & Tarr, 2002). In a dual composite task requiring simultaneous processing of faces and cars, car experts (but not novices) showed behavioral interference of car processing on holistic face processing, as indicated by an attenuated composite-face effect (Gauthier, Curran, Curby, & Collins, 2003). Although the results of the present study establish that early visual experience is necessary for the development of normal holistic processing for faces, further research is required to determine whether early vision is also necessary to preserve the neural substrate that would allow training to induce the later development of holistic processing of nonface objects.

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[1] In a separate experiment, the same deprived patients showed a similar pattern on a composite-face task that required judgments about the bottom halves of faces: no benefit from misaligning the face halves and significantly higher accuracy than the control group on *same*, aligned trials. Thus, whether the composite-face task requires attending to the top or bottom half of the face, deprived patients do not show the composite-face effect.

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