Neural correlates of face discrimination in early development

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May 13, 2009
9.85 Research Proposal

Abstract

Infants are born into a blurry world of indistinct shapes and images, and ffull development of the ability to reliably recognize and distinguish faces is not completed until the late stages of childhood. Morton and Johnson (1991) proposed a dual-process theory, suggesting that while developing children process details before they can process holistically. Here we aim to use fMRI data provide to either support or refute dual-process theory. Second, we aim to determine the nature of the dependence between the OFA and FFA. To achieve these aims, we scan 6 and 10 year-olds and adults as they view images of upright faces, inverted faces, and objects (control). We find evidence that that the OFA is largely responsible for the children's feature-based recognition, and that the FFA is largely responsible for the adults' configuration-based processing recognition. Additionally, our findings provide evidence for feed-forward signaling from the OFA to the FFA. In establishing this model of feed-forward communication, we also present a neural model, which, to the best of our knowledge, accurately explains the results of dual process theory.

Introduction

Infants are born into a blurry world of indistinct shapes and images (Souther & Banks, 1979). By two months, an infant can recognize his mother's face (Bushnell, Sai, & Mullin, 1989; Pascalis, de Schonen, Morton, Deruelle, & Fabre-Grenel, 1995). However, full development of the ability to reliably recognize and distinguish faces is not completed until the late stages of childhood (Carey & Diamond, 1977; Flin, 1985). Morton and Johnson (1991) propose that in the earliest stages of face recognition development, the infant passes through two phases of learning. In the first phase, CONSPEC, the child has an innate expectation of what a face should look like, so that he prefers to view stimuli with markings, which meets the visual specifications of a simple face. In the second phase, CONLEARN, the child learns to recognize faces. During this phase, he is not concerned with the holistic appearance and shape of the face as during CONSPEC, but instead focuses on details of the face, viewing it as a conglomeration of parts.

This dual-process theory is supported by a number of experiments. First, as children develop the unhindered ability to discriminate among objects, they observe the contours of the object to determine its shape (Needham, Baillargeon, & Kaufman, 1997; Bhatt & Waters, 1998; Kestenbaum, Termine, & Spelke, 1987). Similarly, when discriminating among faces, they tend to look at the edges of the face. Although, for an adult, the interior features of the face are more informative for face recognition, young children ignore the expected more informative facial interior (Haith, Bergman, & Moore, 1977). Second, when children less than 2 months old are shown images of faces and scrambled facial features, they show equal preference for each (Maurer & Barrera, 1981; Morton & Johnson, 1991). Both of these findings lend credence to the idea that as children learn to discriminate faces, they process it as a conglomeration of parts, rather than a holistic, innately described specification.

One method often used to investigate facial recognition is the face inversion effect (Yin, 1969). In normal adult visual processing, inversion disproportionately impairs the recognition of faces more than other objects (e.g. house, stick figures) (Diamond & Carey, 1986; Yin, 1969). Adults are especially good at recognizing upright human faces because they are exposed to many faces in the upright configuration on a daily basis (Gauthier & Tarr, 1997). When children are asked to identify inverted faces, they perform equally well in both inverted and upright conditions, indicating that their face processing is entirely feature-based (Freire, Lee, & Symons, 2000; Mondloch, Le Grand, & Maurer, 2002). However, when adults are asked to perform the same task, they show the face-inversion effect. This is likely because their learned configuration of facial features is disturbed, disrupting their normal configuration-based holistic processing. In this case, adults appear to use feature-based processing to identify the face (Freire, Lee, & Symons, 2000). This is consistent with reports that the fusiform face area (FFA) responds to faces rather than the low-level features making up the face (Kanwisher & Tong, 1998).

Two brain regions that are integral in face processing are the occipital face area (OFA) and the fusiform face area (FFA). The OFA is important in processing face parts (Pitcher, Walsh, Yovel, & Duchaine, 2007), and the FFA is essential in holistic face processing (Young, Hellawell, & Hay, 1987; Yovel & Kanwisher, 2004; Yovel & Kanwisher, 2005; Kanwisher, McDermott, & Chun, 1997). Patients lacking an OFA are able to categorize upright faces using configural information, but they are unable to categorize sideways or inverted faces, indicating that the FFA alone is insufficient for normal face processing (Steeves, et al., 2006).

Although the FFA and the OFA are both necessary for normal adult face processing, the nature of the dependence between them is still contested. There are two main theories. First, some assert that the OFA sends information to the FFA via a feed-forward mechanism (Haxby, Hoffman, & Gobbini, 2000; Calder & Young, 2005). Second, others claim that activation in the OFA results purely from feed-back from the FFA (Rossion, Caldera, Seghier, Schuller, Lazeyras, & Mayer, 2003; Rossion, 2008).

The aim of the present study is twofold. First, we aim to provide functional data to either confirm or deny the theory that as children refine their face recognition abilities, they process the face, first as a conglomeration of parts, using the OFA, and eventually as a holistic image, using the FFA. Second, we aim to shed some light on the nature of the dependence between the OFA and FFA. To achieve these aims, we present children three sets of images: (1) intact upright faces, (2) intact inverted faces, and (3) objects (control).

Our predictions are as follow. First, if children indeed use feature-based processes to identify faces as behavioral studies indicate, then we would expect a relative increase in activation of the OFA and decrease in activation of the FFA when compared to their adult counterparts. We also expect this activation to remain constant regardless of whether the children are shown upright or inverted faces. As the children mature, we expect activation in the FFA to increase. Second, if a young child's OFA does show greater activation than the FFA, this implies that the interaction between the OFA and the FFA, at least during development, is feedforward.

Methods

Participants

Subjects will be 6 year-old and 10 year-old children and adults with normal color-vision and acuity. Each age group will have approximately equal numbers of male and female subjects. Each subject will participate in all conditions. Children will come from the Boston area schools, and adult subjects will be recruited from the MIT McGovern subject pool. Both will be paid $30/hr for participation.

Materials

Eighteen different faces will be generated by FACE 3.0 software to replicate the stimuli used by Yovel & Kanwisher (2005). First, there will be six sets of three faces that share the same hair but differ in internal facial information and face outline. The face stimuli will subtend 4.5° (width) × 7° (length) of visual angle. Second, images of the isolated internal features of these faces will be included. Third, chair stimuli will also be included in the experimental task, which allowed us to determine for each subject whether the experimental task showed selectivity to faces (faces > chairs) in the voxels that were identified as face selective by the localizer. Each category of stimuli will be shown in both an upright and inverted configuration for a total of three separate conditions: (1) upright faces, (2) inverted faces, and (3) objects.

Scanning will be done on a 3T coil at the Martinos Imaging Center at the MIT McGovern Institute for Brain Research in Cambridge, MA. A head coil and a Gradient Echo pulse sequence with TR 2 s will be used to minimize the contribution of large blood vessels. Slices oriented parallel to the temporal lobe will be used in order to include both the OFA and FFA.

Procedure

Preparation. Adult subjects were told that that they would be shown pairs of faces – some upright and some inverted, and they would need to press “1” if the two images were identical and “2” if they were different. To make the task more interesting for the children, they were told the following story. “We are looking for spies. We have pictures of many people some of the pictures are upright and some of them are upside-down. Some of the people in the pictures are normal people and some a spies. The pictures of the spies will always appear twice in a row. We need your help to find the spies. To help us, we need you to lie very still, and whenever you see a picture of a spy – two pictures of the same face in a row – we need you t o press '1.' Otherwise we need you to press '2'."

Experiment Design. The procedure used for adults will be based on that of Yovel and Kanwisher (2005). The experiment will consist of five runs of the experimental task and five runs of the localizer, to match activation to brain regions of interest (ROI). These localizers will be presented interleaved with the experimental task so that if children move during the experiment, we can still always locate the ROIs.

Pairs of face or chair stimuli will be presented sequentially either upright or inverted in a randomized order optimized for the extraction of the hemodynamic response in an event-related fast presentation design. The first and second stimuli will be presented for 250 ms, with an interstimulus interval of 500 ms. The next trial will be presented 1 s after the disappearance of the second stimulus. Five runs of the experimental task will be included. Each run will include 24 trials of each condition. In half of the trials, the stimuli will be identical, and in the other half, they will be different. Each stimulus will be presented equally often in the identical and different conditions, so any difference in the fMRI response between conditions must be due to the relationship between the two stimuli in a pair, not the individual stimuli themselves. Same-different responses will be made with a key press. Twenty-four blank trials will be presented intermixed with the experimental trials. Subjects will make a same/different response on each trial, ensuring that they are alert and attending in the scanner.

Discussion

First, six and ten year-old children recognized inverted faces just as well as they recognized upright faces, and the child OFA was significantly more active than the adult OFA when viewing both the upright and inverted conditions. However, the adults exhibited a face-inversion effect; they were significantly less accurate at identifying inverted faces than upright faces. Yet the adult FFA was significantly more active than a child's. Together these results suggest that children recognize faces using a feature-based process localized in the OFA, unlike adults who rely on a configuration-based process localized in the FFA. Second, by comparing activation across age groups, we found six year-olds showed significantly greater OFA activation than adults, while ten year-old children exhibited mid-level activation in both the OFA and FFA, indicating that the OFA sends information to the FFA through a feed-forward process.

First, we aim to confirm the different roles of the OFA and the FFA in face recognition in children and adults. Our behavioral and imaging results considered in conjunction with one another imply a powerful double-dissociation describing the role of the OFA and the FFA in face recognition during development. To the best of our knowledge, this is the first time functional imaging has been used to answer this question.

First, our behavioral finding that adults show a face-inversion while children's task performance remains relatively constant across conditions suggests that children recognize faces using a feature-based, configuration-invariant process, whereas adults recognize faces using a configuration-based process. This finding replicates the findings of several behavioral studies (Freire, Lee, & Symons, 2000; Mondloch, Le Grand, & Maurer, 2002; Kanwisher & Tong, 1998).

Second, our imaging tests show that the child OFA shows significantly greater activation than the adult, and that the adult FFA shows significantly greater activation than the child's. The union of these two results implies that the OFA is largely responsible for the children's feature-based recognition, and that the FFA is largely responsible for the adults' configuration-based processing recognition found behaviorally. This is consistent with previous findings that the OFA processes low-level features, while the FFA is responsible for holistic facial processing (Pitcher, Walsh, Yovel, & Duchaine, 2007; Kanwisher & Tong, 1998; Young, Hellawell, & Hay, 1987; Yovel & Kanwisher, 2004; Yovel & Kanwisher, 2005; Kanwisher, McDermott, & Chun, 1997).

Second, we aim to determine how the respective roles of the OFA and FFA change over the course of development. By comparing ROI activation across age groups, we find that relative activation of the OFA decreases compared to the FFA as the subjects' age increases. This finding lends credence to the theory that the OFA sends information to the FFA via a feed-forward mechanism (Haxby, Hoffman, & Gobbini, 2000; Calder & Young, 2005).

If the OFA signals the FFA via feed-forward communication, then our findings provide a neural model underlying the CONLEARN phase of the theory proposed by Morton and Johnson (1991). These studies suggest that as children learn to recognize faces, they process each face as a conglomeration of parts (Haith, Bergman, & Moore, 1977; Maurer & Barrera, 1981; Morton & Johnson, 1991). The holistic face processing associated with the FFA does not develop until late childhood (Carey & Diamond, 1977; Flin, 1985). Our findings suggest that in early childhood slow, detailed feature-based facial processing activates the OFA, which signals the FFA, strengthening its neural connections. By late childhood, the neural connections in the FFA gain enough strength to produce the quick holistic face processing we use as adults. Since experienced adults do not need to process facial features with the same detail as a child, feature processing in the OFA occurs quickly, leaving most of the face processing to the FFA.

Our findings contradict the theory supported by Rossion et al. (2003) that the OFA signals the FFA via a feedback mechanism. However, he presented imaging data from patients with acquired prosopagnosia as support for his theory. It is possible that because one portion of their temporal lobe was rendered incapable, neural plasticity adapted the network of neurons connecting the OFA and FFA to reverse the direction of signal transmission.

Alternatively, we might consider what another pattern of results would imply. In the case of our first aim: to confirm the different roles of the OFA and the FFA in face recognition in children and adults, our aim was to obtain neural data to confirm pre-existing behavioral results that children recognize faces using feature-based processing and adults using holistic processing. If we had found that the FFA was more active in children than adults, and then we considered in light of pre-existing behavioral data, we might conclude that the FFA was responsible for feature-based processing while the OFA was responsible holistic processing. This would contradict a large body of literature, and consequently would be quite unexpected. In case of our second aim, if our findings were reversed so that the relative OFA-to-FFA activation increase with age, this would imply that OFA-FFA signaling uses a feedback mechanism. This would support the theories of Rossion et al (2003).

However, it also necessary to note that the usual method used to obtain the behavioral results that we used here has been called into question. When asked to identify upright and inverted faces, adults show a face-inversion effect, while children's performance remains constant. Flin (1985) has suggested that this might be due to a floor effect. It is possible that young children's poor performance on recognizing upright faces masked any effects do to inversion. To avoid these floor effects, we might show the images for several seconds to allow maximum recognition time, or allow subjects to practice with the images beforehand. However, this solution presents two concerns: (a) if we give subjects too many advantages to increase their face recognition performance, we are likely to produce a ceiling effect in the groups that perform sufficiently well without an advantage; (b) images in the scanner must be present for a fixed period of time. If the image is presented for too long the subject may forget the previous face or become drowsy. In the future, it maybe useful to add to this experiment by confirming the current behavioral data with a carefully designed experiment, eliminating both ceiling and floor effects.

In sum, this study is the first to use imaging data to suggest that that the OFA is largely responsible for the children's feature-based recognition, and that the FFA is largely responsible for the adults' configuration-based processing recognition. Additionally, our findings provide evidence for feed-forward signaling from the OFA to the FFA. In establishing this model of feed-forward communication, we also present a neural model, which, to the best of our knowledge, accurately describes the widely accepted dual-process theory proposed by Morton and Johnson (1991). We also propose future experiments to further investigate the nature of the connection between the OFA and FFA in early development.

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