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The Development of Face Processing in Autism

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Both behavioral and neuroimaging evidence indicate that individuals with autism demonstrate marked abnormalities in the processing of faces. These abnormalities are often explained as either the result of an innate impairment to specialized neural systems or as a secondary consequence of reduced levels of social interest. A review of the developmental literature on typical and atypical face processing supports a synthesis of these two hypotheses by demonstrating that face processing is an emergent and developmental skill that is heavily mediated by early experience with faces. Individuals with autism may possess central nervous system irregularities that fail to attribute special status to faces, thereby limiting the visual input required for the development of neural regions specialized for face processing.

KEY WORDS: Face processing; autism; development.

INTRODUCTION

Autism is a severe and pervasive neurodevelopmental disorder characterized by impairments in verbal and non-verbal communication, deficits in social interaction, and stereotypic behaviors (DSM-IV; American Psychiatric Association, 1994). Individuals with autism often present stereotyped patterns of behavior, most notably the persistent preoccupation with parts of objects and the prolonged display of repetitive, self-stimulating behaviors. They also exhibit a chronic impairment in the processing of social and emotional information, including abnormalities in the use of eye-to-eye gaze and in the expression and comprehension of facial affect (Baron-Cohen, 1995; Hobson, Ouston, & Lee, 1988a, b). Some characteristics, such as a preference for inanimate objects and a lack of interest in social others, are often evident very early in infancy (Baron-Cohen *et al*., 1996; Kanner, 1943; Osterling & Dawson, 1994; Osterling, Dawson, & Munson, 2002).

Children and adults with autism exhibit irregularities on a wide variety of face processing tasks (Grelotti, Gauthier, & Schultz, 2002; Marcus & Nelson, 2001), including visual scanning, memory for faces and affect recognition. The presence of these behavioral abnormalities is supported by a growing body of neurological evidence that indicates that individuals with autism process faces in a different manner than typical populations (Pierce, Miller, Ambrose, Allen, & Courchesne, 2001; Schultz *et al*., 2000). The current edition of the Diagnostic and Statistical Manual, however, does not list abnormal face processing as a defining feature of disorder, despite including several features that could potentially be associated with impairments in face processing such as deficits in the use of eye-to-eye gaze and facial expression.

Nevertheless, because faces provide humans with a pivotal source of social information, the study of impaired face processing in autism may help explain

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the origins and maintenance of the disorder's deficits in reciprocal social interaction and non-verbal communication. Indeed, abnormal face processing may operate as both a cause and an effect of various social deficits inherent to autism and may therefore offer a window into the disorder's basic affective irregularities. Determining why an individual with autism fails to attend to and effectively process facial information not only provides insight into the origins and maintenance of the social impairments of autism, but also may establish abnormal face processing as an important discriminating criterion for the early diagnosis of the disorder. Additionally, this research enriches our understanding of the more typical trajectory of normal development by exposing specific factors that are necessary for competent face processing to occur. Knowledge in this domain can only contribute to a more thorough understanding of autism's fundamental social impairments, as well as help clarify the specific factors that underlie the normative developmental pattern of face processing. Furthermore, because the etiology of autism is likely heterogeneous, defining specific neuropsychological features of the disorder such as face processing abnormalities may help establish subgroups that are etiologically homogeneous. Identifying the particular neural circuits that underlie various abnormalities of these subgroups can refine our descriptive understanding of the disorder and help to rationally guide behavioral, educational and pharmacological treatments.

The primary aim of this paper is to illuminate the nature of face processing abnormalities in autism by reviewing, comparing, and synthesizing the relevant literature on the development of typical and atypical face processing. By juxtaposing the behavioral and neurological evidence of specific face processing impairments in autism against our current understanding of face processing development in normal populations, this paper discusses the possible causes and consequences of these abnormalities, as well as highlights avenues for future research. The paper proceeds in the following manner. First, evidence for face processing abnormalities in children and adults with autism is presented followed by a summary of studies reporting conflicting results. Viewed together, these findings help specify the manner in which selective aspects of face encoding and representation differ in autism. Second, evidence of face processing abnormalities at the neurological level is included along with a specific emphasis on biological and experiential theories that elucidate the etiology of these neural irregularities. Third, a section that integrates current theories to propose a possible developmental account of abnormal face processing in autism is presented. Finally, the paper ends with a discussion of potential implications of intervention followed by some general conclusions.

One word of clarification is needed before continuing. The term "face processing" will be used in this paper to refer only to the encoding and representation of faces, including an emphasis on the perceptual mechanisms and mnemonic abilities used in this process. Despite evidence that some aspects of facial emotion recognition and processing are impaired in individuals with autism, a review of this extensive literature is beyond the scope of this paper. The topic may be briefly touched upon while discussing studies that include related tasks in their methodology, but in general, the use of the term "face processing" will not include emotion recognition or processing.

ABNORMAL FACE PROCESSING IN CHILDREN AND ADULTS WITH AUTISM

Early qualitative evidence suggested marked differences in the frequency and quality of face processing for individuals with autism (Asperger, 1994/1991; Kanner, 1943). The first experimental investigations of face processing impairments in autism were conducted by Langdell (1978), in which two groups of children with the disorder, aged 9 and 14, performed similarly to controls matched on chronological age and performance IQ on the ability to correctly identify peers from upright photographs of their faces. However, when features of faces were selectively concealed, abnormalities in the face processing of the children with autism were revealed. Both younger and older participants with autism were significantly better than controls at identifying faces from the mouth area presented in isolation, and the younger participants with autism were significantly worse than controls at identifying faces from the eye region alone. In contrast to both groups with autism, controls consistently found the eye region to be the most helpful for identifying faces, a finding that is indicative of a more normative perceptual strategy (Pelphrey *et al.*, 2002; Walker-Smith, Gale, & Findlay, 1977). Hobson, Ousten, and Lee (1988a) later extended upon these findings by determining that, compared to controls, participants with autism used the mouth region more and the eye region less to make judgments concerning identity and emotion recognition. Taken together, these studies suggest that while viewing and encoding a face, these individuals may differentially attend to certain facial features compared to normal populations.

Several recent eye-tracking studies support this claim. Pelphrey *et al.* (2002) recorded the visual scanpaths of adults with high-functioning autism (HFA) as they viewed static photographs of faces. Individuals with HFA spent significantly more viewing time scanning the external areas of the face and significantly less time on the core internal features (i.e., the eyes, nose, and mouth). Consistent with Langdell (1978), this difference was most notable in the decreased amount of time the individuals with HFA spent inspecting the eye region. In another eye-tracking study, Klin, Jones, Schultz, Volkmar, and Cohen (2002) determined that adults with HFA visually attend to dynamic social scenes in an abnormal manner. Compared to controls, individuals with HFA demonstrated reduced attention to the eyes of characters in the scenes, but increased attention to mouths, body parts, and objects. Together, these eye-tracking findings suggest that individuals with autism may employ an abnormal strategy for inspecting faces (however, see van der Geest, Kemner, Camfferman, Verbaten, & van Engeland, 2002 for conflicting results).

Several studies have also reported that individuals with autism exhibit abnormalities in the delayed recognition of faces relative to controls and other visual stimuli (Boucher & Lewis, 1992; de Gelder, Vrooman, & van der Heide, 1991; Hauck, Fein, Maltby, Waterhouse, & Feinstein, 1998). In the only reported study to employ a standardized face recognition assessment, Klin *et al.* (1999) found pronounced deficits in face recognition in children with autism compared to both children with pervasive developmental disorder not otherwise specified (PDD-NOS) and non-PDD groups, even when the groups were matched on both non-verbal and verbal mental age. Thus, the authors conclude that the deficit exhibited by children with autism cannot be attributed to verbal or non-verbal deficits, general task demands, or visual memory deficits. Furthermore, the children with autism exhibited a relatively low correlation between performance and non-verbal intelligence—a correlation even lower than that of controls—suggesting that the face recognition impairment in autism does not appear highly associated with general cognitive ability.

EVIDENCE UNSUPPORTIVE OF FACE PROCESSING ABNORMALITIES IN AUTISM

Although many studies have reported impairments in the processing of faces by individuals with autism, several others have failed to find deficits (Celani, Battacchi, & Arcidiacono, 1999; Davies, Bishop, Manstead, & Tantam, 1994; Teunisse & de Gelder, 1994; Volkmar, Sparrow, Rende, & Cohen, 1989). Furthermore, although several studies claim that recognition impairments are specific to faces and do not extend to non-face stimuli (Boucher & Lewis, 1992; Hauck *et al.*, 1998; Klin *et al.*, 1999), Davies *et al.* (1994) found a more general impairment affecting the processing of non-facial stimuli. In this study, children with autism performed significantly worse than matched controls on facial *and* non-facial tasks, suggesting a more general visual processing impairment. However, the authors did anecdotally note that several children with autism made qualitatively different statements from controls concerning their strategy use for recognizing faces. The comments by the children with autism ("he has his mouth open" for surprise, "he has the same hair" for identity recognition) led the authors to hypothesize that they may be using a more feature-based strategy than control children, suggesting that the two groups may have achieved comparable levels of performance by different means. Nevertheless, because a processing deficit was found for both face and non-face stimuli, the authors argue that autism may be associated with a general perceptual abnormality rather than a selective impairment in face processing.

This interpretation is consistent with Frith (1989), who proposed that individuals with autism experience abnormal perceptual processing known as "Weak Central Coherence" (WCC). This influential theory posits that autism is characterized by an impairment in the integration of environmental information. That is, individuals with autism tend to perceive sensations in a more fragmented manner and, as a result, while they are proficient at processing the details of complex visual stimuli, they demonstrate a deficit at integrating these details into a coherent whole. The WCC argument would posit that abnormal face processing in autism is subserved by a more general perceptual deficit that affects both facial and non-facial stimuli. From this perspective, face processing deficits are neither primary nor domain-specific in the disorder. While Davies *et al.* (1994) supports such a conclusion, the findings of other studies do not (Boucher & Lewis, 1992; Hauck *et al.*, 1998).

Although it is difficult to conclude why some studies have found face processing deficits in autism while others have not, differences in experimental tasks, participant ages, and control group criteria likely contribute to the ambiguity. A variety of methodologies have been employed in these studies—most of which have not been replicated—and only a few have utilized standardized measures of face processing (Klin *et al.*, 1999; Teunisse & de Gelder, 1994). Furthermore, many studies tested individuals across a wide range of ages and abilities, making it difficult to draw conclusions about age-related changes or effects of functioning level. Additionally, some studies have tested individuals with "classic" autism, while others have focused on those who are high-functioning or who have Asperger syndrome. These differences in sample composition have made comparisons across studies more difficult and may contribute to the presence of non-replicated findings. Moreover, because of experimental demands, there may have been an overrepresentation of older age groups and individuals with high-functioning autism and Asperger syndrome, making attempts to draw general conclusions about face processing in autism all the more complicated.

Of the studies that failed to find deficits, many employed tasks that may not have elicited group differences in performance because each could be achieved based on feature-based perceptual strategies alone (Davies *et al.*, 1994; Teunisse & de Gelder, 1994; Volkmar *et al.*, 1989). Only one implemented a delayed-response methodology (Celani *et al.*, 1999), and even here the delay was quite brief and may not have completely minimized the effectiveness of feature-based strategies. Tasks that require the participant to process the configural and holistic properties of faces, or interpret meaning in them such as affect recognition, may reveal larger effects than those that simply require the analysis of superficial similarities and differences in stimuli. Control groups similarly have been problematic, as there has been an inconsistency in the selection of appropriately matched controls. Varied criteria have been used, including chronological age, mental age, non-verbal IQ, and verbal IQ. Samples sizes have also been quite small and have frequently generated very small effects.

Further, Klin *et al.* (1999) has suggested that these abnormalities may not always translate into impaired performance on experimental tasks because some individuals with autism, especially those who are older, may develop compensatory strategies for processing faces. Indeed, the fact that adults with autism display less severe face recognition deficits than children with autism relative to matched control suggests that over time these individuals may develop alternative face processing mechanisms that help to minimize their impairment. Longitudinal research is needed in order to assess how developing compensatory strategies affects face processing abilities for individuals with autism.

THE ENCODING AND REPRESENTATION OF FACES IN CHILDREN WITH AND WITHOUT AUTISM

Even if studies conflict concerning the performance of individuals with autism on a variety of face processing tasks, they do suggest that the manner in which these individuals process faces is abnormal. That is, when assessing the face processing performance of individuals with autism, it is not just the question of *how well* that is important, but also the question of *how*. While overall face recognition performance on upright faces indicates that individuals with autism may sometimes perform similar to controls, the process by which they reach their judgments may be vastly different (and perhaps even different from one another). As detailed previously, when one analyzes the method by which individuals with autism process faces, a number of abnormalities emerge: they employ disorganized visual scanning patterns, they rely to a greater degree on the mouth region and to a lesser degree on the eye region for identity recognition, and they do not exhibit a mnemonic advantage for faces over objects. These findings indicate that individuals with autism are abnormal in their encoding and representation of faces and suggest a failure to treat the face as a special stimulus, regardless of their actual performance on particular tasks.

This abnormality in facial encoding and representation is perhaps most evident in the reduced tendency of individuals with autism to demonstrate an inversion effect for faces. For typical adults, face recognition accuracy declines sharply when stimuli are presented upside-down, although object recognition is minimally affected by orientation (Yin, 1969). Studies have demonstrated that this facial inversion effect is not present to the same degree in autism and that compared to controls, individuals with autism often perform better at the recognition of inverted faces (Hobson *et al.*, 1988a; Langdell, 1978; Tantam, Monaghan, Nicholson, & Stirling, 1989). Although this suggests that faces and objects may be processed more similarly in autism than in typical development, there has been surprisingly little research aimed at determining the specific differences in the perception and encoding of faces that contribute to this abnormality.

The explanation for the inversion effect in normal adults offered by Yin (1969) and many researchers since (Diamond & Carey, 1986; Farah, Wilson, Drain, & Tanaka, 1998; Rhodes, 1988) maintains that faces, unlike objects, are processed primarily in a holistic manner (i.e., the obligatory processing of all features simultaneously). That is, faces are perceived and processed not only by their individual parts, but also as an overall template in which the spatial relationships between features take on additional significance. Inversion disrupts this form of processing, and as a result, upside-down faces are perceived and processed in a more piecemeal, feature oriented manner typically used for objects. Subsequent research has refined Yin's findings by determining that configural information (i.e., the spatial distance between the eyes, and between the mouth and nose) is sensitive to facial inversion while featural information (i.e., the shape and size of the eyes, nose, and mouth) is processed similarly regardless of orientation (Freire, Lee, & Symons, 2000).

Interestingly, the inversion effect increases with age for typically developing individuals. While the accuracy rates of younger children are not impaired for face recognition when faces are presented upside-down, both older children and adults reveal a significant decrease in recognition rates when faces are inverted (Carey, 1996). The prevailing explanation for this phenomenon is that young children disproportionately rely upon a featural or piecemeal strategy for encoding and remembering faces, while children at least 10 years of age and adults demonstrate a greater dependency upon facial configurations (Carey & Diamond, 1994; Diamond & Carey, 1986). Because the inversion of a face disrupts configural but not featural processing in normal adults (Freire *et al.*, 2000), an age-related increase in the inversion effect may reflect a developmental trend towards a greater reliance upon the configural properties of faces. Indeed, while the processing of facial features is relatively mature in young children, the processing of the configural relations among them improves into young adulthood (Mondloch, Le Grand, & Maurer, 2002). This finding suggests that an increasing sensitivity to configural information in faces may in part underlie the more sophisticated levels of face processing found in adulthood and serve as a marker for a developing visual expertise of faces. Indeed, a refined sensitivity to configural information has been found to differentiate face processing from typical object processing in normal adults (Gauthier & Tarr, 1997; Gauthier, Williams, Tarr, & Tanaka, 1998; Tanaka & Gauthier, 1997).

Although yet to be experimentally determined, a number of sources suggest that the normative pattern of age-related improvements in the processing of configural information in faces may not occur for individuals with autism. First, the lack of an inversion effect in this population not only indicates a failure to encode or process faces in the same manner as typically developing individuals, but also suggests a reduced reliance on configural face processing. Specifically, because inversion disrupts configural but not featural face processing, the lack of an inversion effect in individuals with autism implies an insensitivity to configural information in faces. Indeed, while both individuals with autism and typically developing young children do not show an inversion effect for faces (Carey, 1996; Diamond & Carey, 1986), only individuals with autism do not exhibit an inversion effect in adulthood (Hobson *et al.*, 1988a; Langdell, 1978; Tantam, Monaghan, Nicholson, & Stirling, 1989), suggesting that they do not develop an expertise for faces and may not learn to treat them as a special category of stimuli.

Second, a recent study suggests that individuals with prosopagnosia, a condition in which one can correctly label objects but cannot distinguish among faces, are impaired at the detection of configural changes to faces relative to the detection of featural changes (Barton, Press, Keenam, & O'Connor, 2002). Given that individuals with prosopagnosia who have lesions to the fusiform gyrus (FG) demonstrate deficits in the perception of configural information in face but not non-face stimuli (Barton *et al.*, 2002; Duchaine, 2000), we might similarly anticipate such deficits in individuals with autism because this population exhibits little to no activation in the FG in response to faces (Shultz *et al.*, 2000). This neurological impairment will be detailed in subsequent sections.

Third, individuals with autism do not appear to perceive faces holistically (Joseph & Tanaka, 2002), a style that elicits configural processing and is reserved for targets of visual expertise (Gauthier *et al.*, 1998). Typically developing individuals as young as 6 years of age are more successful at identifying the top half of a face when it is offset from the bottom half of a different face than when the two halves are aligned, presumably because when together, the two halves fuse to form a new perceptual gestalt (Carey & Diamond, 1994; Young, Hellawell, & Hay, 1987). In contrast, Joseph and Tanaka (2002) found that a group of children with autism performed abnormally on a composite face task used to measure holistic processing. In this study, the authors tested the ability of children with HFA to recognize a particular facial feature, learned in the context of a whole face, either in isolation or in its original presentation within a whole face. In contrast to control children who demonstrated an advantage for recognizing all features presented in a whole face rather than in isolation, children with HFA only demonstrated a whole-face advantage for mouths, and were profoundly impaired when face recognition depended on the eyes.

Finally, unlike typically developing children, individuals with autism may not transition from a bias for featural face elements to a more holistic processing style. Schwarzer (2000) has shown that young children will categorize faces based on a salient feature, while older children and adults will do so based on overall similarity. In contrast, objects continue to be categorized in a featural manner by adults (Ward, 1989). Because young children show a distinct preference for the featural categorization of both faces and non-facial stimuli, Schwarzer (2000) concludes that over time, increased age and experience with faces encourage children to categorize faces in a more holistic manner. Whether this transition from featural to holistic categorization of faces fails to occur in autism has not been explicitly tested, although indirect evidence (i.e., the lack of an inversion effect) suggests that individuals with autism may maintain a featural approach in adulthood. Weeks and Hobson (1987) supports this conclusion by demonstrating that children and young adults with autism, aged 8–22, tend to sort a series of facial photographs according to the hats they are wearing, while controls matched on chronological age and verbal ability sort the same photographs in a more holistic manner (i.e., by the expressions being displayed). Also, as mentioned previously, featural processing is implied by studies demonstrating a disproportionate emphasis on the mouth region for identity and affect recognition (Klin *et al.*, 2002; Langdell, 1978; Tantam *et al.*, 1989).

On the whole, these studies suggest that individuals with autism may be impaired at the processing of configural facial information relative to both featural facial information and configural non-facial information because they do not demonstrate an expertise for faces at either the behavioral level (i.e., a lack of an inversion effect and a deficit in holistic face processing) or the neural level (i.e., minimal activation in the fusiform gyrus). Such an impairment would indicate a possible breakdown in the development of a specialized face processing system in autism. A failure to effectively encode and represent configural facial information would reflect an inability to process the face differently from non-face stimuli and suggests that unlike typical populations individuals with autism may rely primarily upon a feature-based strategy for processing faces. Such a processing style would almost necessarily impair both identity recognition (where, in the absence of a salient featural cue, configural and holistic processing becomes important) and emotion recognition (where the simultaneous processing of multiple features may aid in the detection of facial affect).

NEUROLOGICAL EVIDENCE

Several neuroimaging studies suggest that the brains of individuals with autism process faces in a fashion more typically found in object processing (Pierce *et al.*, 2001; Schultz *et al.*, 2000). This research indicates that the fusiform gyrus (FG), a brain region found to activate maximally to human faces in typical populations (McCarthy, Puce, Gore, & Allison, 1997; Tong, Nakayama, Moscovitch, Weinrib, & Kanwisher, 2000; however, see Schultz *et al.*, 2003 for evidence that the FG may activate to a broader range of social stimuli), exhibits reduced activation in persons with autism in response to the viewing of unfamiliar faces. Activation patterns for object stimuli, however, appear normal. Interestingly, while viewing faces, individuals with autism were found to demonstrate greater activation in an atypical cortical location usually involved in object processing, suggesting that the perceptual processing of faces in autism is more like the perceptual processing of objects in persons free from social disability.

Two predominant theories for the etiology of this abnormality have been proposed (Pierce & Corchesne, 2000). One, there exists a genetically determined cortical system specialized for face processing

(Farah *et al.*, 1998; Farah, Rabinowitz, Quinn, & Liu, 2000), and the existence of autism somehow disrupts the formation of this system. And two, the development of a face processing system is heavily dependent on experience. Reduced social interest in autism would impair normal levels of engagement with faces and lead to the development of face processing abnormalities.

Evidence for an inborn specialized system for face processing, as emphasized by the first theory, comes from several sources. First, typically developing neonates prefer face-like stimuli to other visual patterns of similar complexity (Goren, Sarty, & Wu, 1975; Morton & Johnson, 1991) and are capable of recognizing individual faces (Johnson, Dziurawic, Ellis, & Morton, 1991; Pascalis, de Schonen, Morton, Deruelle, & Fabre-Grenet, 1995). Second, a recent study indicates that the FG is activated during face processing early in life. Tzourio-Mazoyer *et al.* (2002) presented photographs of women's faces to 2-month-old infants and, using positron emission tomography (PET), found that their brain activation patterns were similar to those of adults, including activation in an anatomical location approximating the adult FG. Although such a finding does not confirm the existence of an inborn specialized brain region for face processing—it can be argued that 2 months is enough time for the beginnings of this system to emerge—it does suggest that the neural system underlying face processing in adulthood may be active, in whatever nascent capacity, early in infancy. This explanation would posit that inborn neurostructual differences in the brain of an individual with autism fail to differentiate the face as a "special" class of visual stimulus. The existence of such an impairment would prevent an individual with autism from attributing preferential significance to the human face over other visual stimuli in the environment, a process that would invariably impede normative social development.

The second theory argues that the special status given to the human face for typical populations is not an inborn trait, but rather a product of experiential expertise and regular exposure to human faces. Researchers who endorse this hypothesis argue that the FG activates not only in response to human faces, but also in response to any stimulus that is expertly processed by a particular individual. For example, Gauthier and her colleagues have demonstrated that experts of non-face categories such as birds and cars exhibit greater FG activation than do non-expert controls (Gauthier, Skudlarski, Gore, & Anderson, 2000), and that training participants to become an expert in a novel class of objects (a collection of original creatures she has deemed "greebles") leads to increased activation in the fusiform gyrus (Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999). From this perspective, individuals with autism may not process faces as "special" because they spend reduced amounts of time engaged in face perception from birth, and as a result, never develop a visual expertise for faces.

As Pierce and Courchesne (2000) have pointed out, the origin of the irregular brain activation pattern seen in autism in response to faces may illuminate another controversial question within the face processing literature—is the FG a modular brain region specialized for the processing faces or is it an experience-driven neural substrate devoted to any well-developed visual expertise? If the FG is not exclusively selective for faces but rather more flexibly underlies the expert processing of any visual stimulus, then individuals with autism should demonstrate activation in the FG within a particular category of expertise. Because a common characteristic of autism is the presence of an intense and narrow focus on a particular area of interest, this question could be addressed without significant difficulty. The presence of FG activation in such individuals while viewing stimuli within their area of expertise would suggest that the neural system associated with face processing in typical populations is not functionally impaired in autism, but rather that faces are not processed at expert levels for these individuals. Explanations for this discovery would likely involve developmental evidence for reduced attention to faces, differential processing styles, or abnormal learning mechanisms.

As noted by Pierce and Courchesne (2000), this question could further be addressed in the context of Gauthier's "greeble" task (Gauthier & Tarr, 1997). If individuals with autism trained to be experts in the processing of greebles demonstrate an increase in FG activation in the same manner that typical populations exhibit, this would also lend support to the conclusion that this neural region is not functionally abnormal in individuals with autism, but rather minimally activated during face processing because of an insufficient expertise for faces. Conversely, if the FG remains dormant even after extensive training with greebles, this would support the contention that this brain area is functionally impaired in individuals with autism. A similar paradigm could be implemented using faces. If individuals with autism can be trained to process faces at expert levels, and subsequently demonstrate more normative levels of activation in the FG, it could be concluded that a lack of expertise and not localized neural impairment is responsible for the minimal activation patterns found for this region in response to faces. Additionally, although admittedly speculative at this point, it is conceivable that individual differences in face processing performance may in part be explained by quantitative differences in neurological activation. Discovering the degree to which FG abnormality in individuals with autism correlates with performance on face processing tasks, and perhaps more broadly, with the level of impairment experienced in the social world, would help elucidate the neural underpinnings of impaired social cognitive functioning in autism. Future investigations are needed in order to determine the level of plasticity in the face processing system, both in normal individuals and individuals with autism, in order to guide intervention efforts.

Also, an abnormal neurological profile for face processing by individuals with autism ultimately may provide an early indication of the possible presence of the disorder. Motivated by the need to develop a reliable early measure for the detection of the disorder, Dawson *et al.* (2002) introduced an effective method for discriminating 3- to 4-year-old children with autism from both typically developing individuals and those with developmental delay. Using high density ERP, these authors demonstrate that in contrast to both typically developing children and children with developmental delay, children with autism do not exhibit differential brain activation patterns for faces as compared to objects. This finding compliments behavioral studies demonstrating that children with autism process faces abnormally and provides the first compelling neural evidence that a face processing impairment exists early in life for these individuals.

A DEVELOPMENTAL APPROACH FOR UNDERSTANDING FACE PROCESSING ABNORMALITIES IN AUTISM

Theories aimed at understanding the etiology of an abnormal face processing system in autism have often focused on a general nature/nurture dichotomy: either individuals with autism enter the world with an impairment in innate face processing mechanisms or they develop this impairment through a failure to receive sufficient experience-expectant facial input. A developmental integration of these theories may provide a more thorough and profitable account of face processing abnormalities in autism. Such an approach ultimately necessitates an examination of face processing during infancy in order to specify potential possible breakdowns in the development of face processing in individuals with autism.

Face Processing in Infants with and without Autism

Facial stimuli seem to be of particular interest for normally developing infants (Koenig, Rubin, Klin, & Volkmar, 2000). Researchers have demonstrated a preference in newborns for face-patterned stimuli over equally complex stimuli that are free of social content (Goren *et al.*, 1975; Johnson *et al.*, 1991). Newborns will preferentially orient to—and track further in their periphery—stimuli that maintain the configuration of a face vs. stimuli that rearrange or invert these properties. Immediately after birth, infants rapidly begin to acquire information about faces and their identities. Babies only a few days old will attend longer to a static image of the mother's face than a stranger's face, even when controlling vocal and olfactory clues (Bushnell, Sai, & Mullin, 1989), indicating that even very young infants are able to recognize and discriminate individual faces. However, this preference for the mother's face disappears when the outer contours such as the neck and hairline are masked. In other words, these infants are identifying faces based on their outer rather than inner characteristics (Pascalis *et al.*, 1995), suggesting the presence of a very primitive recognition system.

Research investigating the visual scanpaths of typically developing infants supports this finding. During the first month of life, infants tend to scan the outline of the face and regions of high contrast (i.e., the hairline and the eyes), but by the second and third months of life, they become increasingly adept at scanning the internal features such as the eyes, nose, and mouth (Haith, Bergman, & Moore, 1977; Maurer & Salapatek, 1976). Infants become increasingly knowledgeable about individual faces during the first few months of life and soon begin to process them differently from other visual stimuli. Using a habituation task, de Haan, Johnson, Maurer, and Parrett (2001) demonstrated that 1-month-old infants are capable of discriminating and recognizing individual faces. By 3 months of age, they can recognize an average prototype of four previously viewed novel faces, suggesting that even at this young age, infants are able to form a facial category based on faces they have previously encountered. By 6 months of age, brain activity measured by event related potentials demonstrates that infants not only differentiate familiar from unfamiliar faces, but also differentiate faces from both familiar and unfamiliar objects (de Haan & Nelson, 1999). By 12 months of age, infants are attending to the faces of others in order to achieve a variety of socially motivated goals, including joint attention (Mundy & Neal, 2000) and social referencing (Baldwin & Moses, 1996). Collectively, this evidence indicates that the human face represents a salient and increasingly informative visual stimulus for normally developing infants.

In contrast, children with autism are developmentally delayed on social milestones that involve looking at faces to gauge the reactions of another person or to share interest and attention in objects and events (Mundy & Neal, 2000). Furthermore, children with autism do not share the same level of attraction to the human face as typically developing children (Dawson *et al.*, 2002; Grelotti *et al.*, 2002; Marcus & Nelson, 2001). During play sessions, young children with autism spend less time looking at people and more time looking at objects compared to controls (Swettenham *et al.*, 1998). Even when compared to developmentally matched children with Down Syndrome, they frequently fail to orient to stimuli, a discrepancy that is even more pronounced for social stimuli (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998).

Is this high level of social inattention already present during infancy for individuals with autism? Unfortunately, this question is difficult to address because autism is rarely diagnosed before 2 or 3 years of age. Symptoms of autism are often not salient until late infancy, when language delays and impairments in social behavior become increasingly apparent. A few studies have, however, employed creative measures to circumvent this problem and have successfully conducted observations of infants later diagnosed with autism. For example, Dawson, Osterling, Meltzoff, and Kuhl (2000) longitudinally observed an infant at risk for autism due to a high incident rate of the disorder in the family. Among a number of abnormal characteristics, the authors report that the infant exhibited poor eye contact and reduced social engagement during the second half of the first year. By 1 year of age, the infant demonstrated decreased and occasionally avoidant eye contact and a failure to engage in, use, or respond to social interaction and joint attention. Interestingly, at two and a half months, the infant exhibited age-appropriate social behavior, including responsive smiling and vocalizations. This suggests that for some infants later diagnosed with autism, social interest may appear normal very early in life but, for unknown reasons, is disrupted soon thereafter.

Other researchers have analyzed the home movies of children's first birthday parties and found that a failure to attend to faces discriminated 12-month-olds with autism from those who were developing normally (Baranek, 1999; Osterling & Dawson, 1994). Likewise, Osterling *et al.* (2002) employed a similar methodology and determined that infants later diagnosed with autism can be differentiated from infants with mental retardation at 1 year of age by the amount of time they spend looking at other people. Taken together, these studies, both prospective and retrospective in design, suggest that infants with autism may differ strongly from typically developing infants in the manner and frequency with which they engage in face processing. It is important, therefore, to determine how reduced experience with faces during infancy might affect the development of the face processing system.

Infancy as a Sensitive Period for the Development of Face Processing

One of the most influential theories of face processing development during infancy argues that a primitive and experience-independent subcortical system, termed "Conspec," causes newborns to preferentially attend to face-like stimuli, while a separate cortical system, "Conlern" (Johnson & Morton, 1991), is modified through visual input to learn about faces and their identity. Conspec is thought to bias the visual input an infant receives, thereby setting up the still plastic Conlern to begin developing the specialized face processing circuits seen in adults. As such, this theory acts as a synthesis of nature–nurture explanations, accounting for both neonate visual behavior and the emergence of more mature face processing capabilities.

The transition from Conspec to Conlern has been elucidated by the "experience expectant" model of visual development (Nelson, 2001), which argues that humans enter the world with a neural system prepared to become specialized for faces, but only through exposure to faces does such perceptual and cortical specialization occur. If the system fails to receive this visual input, or if the neural system is damaged so that it cannot properly process environmental experience, the development of a specialized face processing system may not occur (Marcus & Nelson, 2001). This model suggests that infancy may constitute a sensitive period in which exposure to faces sets up a neural architecture necessary for long-term competency in face processing. Although the nature and duration of this sensitive period is unclear, its existence is supported by several studies.

Pascalis, De Hann, and Nelson (2002) measured the ability of 6-month-olds, 9-month-olds and adults to discriminate between photographed pairs of both human and monkey faces and found that while younger infants are able to discriminate individual faces of both species, older infants and adults are only able to discriminate human faces. This finding suggests that with increased experience with human faces, infants undergo a perceptual narrowing effect that tunes their neural networks for more sophisticated species-specific face processing. The authors argue that this process is similar to findings in the language development literature indicating that between 6 and 10 months of age the ability for infants to discriminate between native phonemes increases while the ability to discriminate between foreign phonemes decreases (Kuhl, Williams, Lacerda, & Stevens, 1992). In both cases, plastic neural networks are altered through early experience, becoming increasingly specialized. It is interesting to note, however, that at the time of this writing whether or not the emergence of conspecific facial specialization could be modified through early exposure to faces of other species has yet to be determined.

In another study demonstrating a critical relationship between early visual experience and long-term face processing abilities, Le Grand, Mondloch, Maurer, and Brent (2001) measured configural and featural face processing in adolescents who, as infants, were deprived of visual input for the first 2–6 months of life due to bilateral congenital cataracts. Using a delayed face recognition paradigm in which participants judged whether a face was the same or different from one seen 300 milliseconds previously, the authors found that these individuals performed similarly to age-matched controls on the processing of featural face information but significantly worse at the processing of configural face information. Importantly, this impairment in configural processing appears to be specific to faces, as the same individuals exhibited normal encoding of configural information in geometric patterns. A follow-up study refined this finding further by determining that the cataract patients presented impairments at the matching of facial identity when head orientation or facial expression was altered (a skill that necessarily requires the processing of second-order configural relationships), but not on other face processing skills, such as affect recognition, lip-reading and direction of gaze (Geldart, Mondoloch, Maurer, de Schonen, & Brent, 2002).

Collectively, these findings indicate that early visual experience is necessary for long-term competency in some, but not all (i.e. configural, but not featural), aspects of face processing. Furthermore, they are consistent with the hypothesis that early visual input facilitates the development of specialized cortical systems (Johnson & Morton, 1991; Nelson, 2001). If these cortical systems develop in the absence of visual input, as was the case for the patients born with cataracts for the first 2–6 months of life, lasting impairments in face processing may result. Whether it is early visual experience in general, or early visual experience with faces more specifically, that is needed in order to develop long-term competency in face processing remains unclear. Clarification on this issue is critically important for understanding the origin of face processing abnormalities in autism. Unlike cataract patients, individuals with autism are not deprived of general visual input early in life. They may, however, experience minimal visual input of faces.

Early Visual Experience and Face Processing in Autism

Le Grand *et al.* (2001) and Geldart *et al.* (2002) suggest that atypical visual experience during infancy may disrupt experience-expectant development of face processing cortical regions and deleteriously affect the emergence of a specialized face processing system. Because infants with autism may lack an attraction to—or perhaps even actively avoid—the human face (Baranek, 1999; Osterling & Dawson, 1994; Osterling *et al.*, 2002), it is possible that specific developing neural systems devoted to face processing are denied experience-expectant stimulation. If this is the case and early visual experience with faces is required for the development of a specialized face processing system, adults with autism should perform similarly to the cataract patients in Le Grand *et al.* (2001) and Geldart *et al.* (2002) by exhibiting deficits in the ability to perceive configural facial information compared to controls. However, if visual input more broadly is needed for long-term competency in configural face processing, adults with autism should not show any impairments in this domain. Le Grand *et al.* (2001) and Geldart *et al.* (2002) cannot dissociate between these two potential causes because their sample of cataract patients were concurrently deprived of both early exposure to faces and general visual experience. A finding of configural face processing deficits in adults with autism would help clarify the findings of their cataract patients by implicating reduced exposure to faces in early infancy, rather than a reduction in general visual experience, as a cause of later deficits in configural face processing.

Additionally, if Pascalis *et al.* (2002) are correct that face processing becomes increasingly species-specific during typical infant development due to an experientially driven perceptual narrowing effect, individuals with autism who exhibited reduced engagement with faces as infants may retain a more successful ability to discriminate the faces of other species relative to controls. Such a finding would suggest a failure in autism to develop a system specialized for faces as found in typical individuals, and offer support for theories implicating infancy as a sensitive period for face processing development.

Why Might an Infant with Autism Exhibit a Reduced Attraction to the Human Face?

Le Grand *et al.* (2001) and Geldart *et al.* (2002) hold important implications for the study of face processing abnormalities in autism because they indicate that the sophisticated face processing abilities of typical adults are experientially tied to normal levels of visual input during infancy. If specific visual input is needed for the normative development of a face processing system, individuals with autism may demonstrate impairments in this domain because of abnormalities in social attention mechanisms that typically orient infants to faces and attribute them value. It is well known, for example, that children and adults with autism demonstrate significant levels of gaze avoidance. While normally developing infants may be naturally attracted to the eyes of others because of their preference for high levels of contrast, curves, and contours (Johnson, *et al.*, 1991), infants with autism may not share this same level of attraction. Several autobiographical accounts suggest that decreased eye contact by individuals with autism may arise out of an aversion to the rapid motion inherent in facial posturing. At least two authors with high-functioning autism have reported that the darting motion of the eyes is an especially overwhelming stimulus for them to process (Grandin, 1986; Williams, 1992).

Furthermore, recent neurological evidence suggests that individuals with autism may possess abnormalities in the amygdala, a brain region involved with assessing the emotional significance of a stimulus (Brothers, 1990). The amygdala is believed to attribute saliency to social stimuli and underlie reward mechanisms involved in the engagement of the social world (Dawson *et al.*, 2002). A number of studies have shown that the amygdala may be structurally and functionally abnormal in individuals with autism. Children with autism have enlarged amygdalas compared to controls, even when accounting for increased cerebral volume (Sparks *et al.*, 2002), and individuals with HFA who demonstrate deficits in the recognition of identity, gaze detection, and facial affect, similarly demonstrate an enlargement of the amygdala, suggesting that increased amygdala size may help explain individual differences in the severity of autistic symptomatology (Howard *et al.*, 2000). Additionally, Bachevalier (1994) has reported that the best animal model for autism is created when the amygdala is lesioned.

Several other studies have linked abnormal amygdala functioning in autism to impairments in affect recognition. While making judgments concerning facial affect, the amygdala activates less for individuals with autism than for controls (Baron-Cohen *et al.*, 2000). Adolphs, Sears, and Piven (2001) have shown that patients with lesions to the amygdala are comparable to individuals with HFA on a number of affect recognition tasks. Both groups demonstrate a selective deficit in the processing of negative but not positive facial emotion, especially in the judgment of fear, while also exhibiting abnormalities in the attribution of trustworthiness. The authors propose that this pattern of results suggest that individuals with autism may be expected to exhibit abnormalities in amygdala functioning.

Invariably, a congenital abnormality in amygdala functioning would contribute to a reduced interest in social processing and result in less frequent engagement with faces. Developing neural systems devoted to face processing would then be denied experience-expectant visual input, which ultimately may prove necessary for establishing the neural architecture used for long-term face processing competency. From this perspective, difficulties in the processing of faces are not a primary deficit in autism, but rather a secondary result of decreased social engagement caused by an abnormal neurological profile. Nevertheless, face processing abnormalities may still constitute a discriminating characteristic of the disorder and provide a profitable entry point for clinical intervention.

Implications for Intervention

Early intervention in the abnormal face processing trajectory of autism may provide cumulative social benefits because many aspects of face processing, including the detection of gaze and the deciphering of facial emotion, contribute to the development of more sophisticated social-cognitive processes such as joint attention, social referencing and theory of mind. Although intervention during infancy may not always be feasible considering that the large majority of diagnoses are not made until at least 2 years of age, action taken at later ages may still prove valuable. Many have argued that the neural system underlying specialized face processing is not crystallized at any point in development, but rather is flexible and capable of processing any visual stimulus of expertise (Gauthier *et al*., 2000; Tanaka & Gauthier, 1997). If it is indeed the case that differential experience with faces over the course of development influences the neurological wiring involved in face perception and processing, implementing behavioral interventions that encourage individuals with autism to engage with and process faces may stimulate and benefit affected brain regions (Dawson *et al*., 2002). Similarly, a ''greeble'' methodology could be employed to train children and adults to process faces at a more expert level. If, however, it turns out that the face processing neural system proves resistant to intervention (i.e., it is not as plastic as some have suggested), help could still be given by teaching compensatory strategies for identifying and processing faces.

CONCLUSIONS

Although reported findings remain equivocal concerning the nature of a face processing deficit in autism, both behavioral and neuroimaging evidence suggest that individuals with the disorder employ abnormal strategies for encoding and representing faces. Explanations for the origin of this abnormality have focused on one of two alternatives: either individuals with autism experience face processing impairments from birth resulting in a failure to attribute special status to facial stimuli or, conversely, their primary deficit is a reduced level of social interest that in turn deleteriously affects the development of a specialized face processing system. Recent evidence supports a synthesis of the two hypotheses by demonstrating that face processing is an emergent and developmental skill, meditated by exposure and experience with faces, particularly during early infancy. Abnormalities in the central nervous system of individuals with autism may fail to attribute social meaning to faces, thereby reducing experience-expectant visual input required for the development of specialized face processing abilities.

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