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REPORT

Development of emotional facial recognition in late childhood and adolescence

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Abstract

The ability to interpret emotions in facial expressions is crucial for social functioning across the lifespan. Facial expression recognition develops rapidly during infancy and improves with age during the preschool years. However, the developmental trajectory from late childhood to adulthood is less clear. We tested older children, adolescents and adults on a two-alternative forced-choice discrimination task using morphed faces that varied in emotional content. Actors appeared to pose expressions that changed incrementally along three progressions: neutral-to-fear, neutral-to-anger, and fear-to-anger. Across all three morph types, adults displayed more sensitivity to subtle changes in emotional expression than children and adolescents. Fear morphs and fear-to-anger blends showed a linear developmental trajectory, whereas anger morphs showed a quadratic trend, increasing sharply from adolescents to adults. The results provide evidence for late developmental changes in emotional expression recognition with some specificity in the time course for distinct emotions.

Introduction

Faces convey an abundance of information about the internal state of an individual. Appropriately decoding facial expressions aids in an individual's ability to understand and appropriately adapt to the social environment and thus is a crucial part of social interactions. Gaining a greater understanding of the normal developmental trajectory of emotional facial recognition may help in the early identification and possible treatment of affective disorders such as autism, depression, and anxiety disorders.

The majority of research on facial expression development has focused on infancy and early childhood. Infants aged 4–9 months can discriminate a number of facial expressions, including happiness, anger, fear, sadness, and surprise (Caron, Caron & MacLean, 1988; Nelson, 1987; Serrano, Iglesias & Loeches, 1992). Through the preschool and early primary school years, performance increases have been observed for correctly recognizing and labeling various emotional facial expressions (Camras, 1980; Camras & Allison, 1985; Harrigan, 1984; Odom & Lemond, 1972; Tremblay, Kirouac & Dore, 2001). While there is much research on facial expression recognition in infancy and early childhood, it is uncertain whether facial expression recognition abilities continue to develop. Some reports in the literature imply that few interesting changes in facial emotion recognition occur after ages 5 (Harrigan, 1984), 7 (Kirouac, Dore & Gosselin, 1985), or 10 (Tremblay *et al.*, 2001). However, it is possible that the methods used to index facial emotion processing in children were prone to ceiling effects in performance. For example, some tasks with older children use labeling procedures such as choosing the emotion that matches a face from a list or picking the face that matches a story (see Vicari, Reilly, Pasqualetti, Vizzotto & Caltagirone, 2000). Many studies also use schematic facial stimuli, which may be oversimplified (Gross & Ballif, 1991) relative to real actors portraying validated facial expressions. While older children and adolescents may be able to recognize and label prototypical category exemplars of emotions, they might not be as sensitive to nuances in facial expression conveyed in blends of emotions or emotions of lesser intensity.

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Describing this late developmental trajectory could shed some light on the emotional difficulties displayed during the teenage years, including clashes with authority and parental conflict (Flannery, Montemayor, Eberly & Torquati, 1993), as well as provide a means to track neuropsychiatric disorders such as major depression and anxiety, whose rates increase during adolescence (Costello, Mustillo, Erkanli, Keeler & Angold, 2003; Pine, Lissek, Klein, Mannuzza, Moulton, Guardino & Woldehawariat, 2004).

Emotional face processing involves a network of brain areas, including the fusiform gyrus, prefrontal cortices (PFC), insula, and the amygdala. The fusiform gyrus shows specialization in activation for faces (Kanwisher, McDermott & Chun, 1997; Puce, Constable, Luby, McCarthy, Nobre, Spencer, Gore & Allison, 1995) that is enhanced by emotional expression (Breiter, Etcoff, Whalen, Kennedy, Rauch, Buckner, Strauss, Hyman & Rosen, 1996; Critchley, Daly, Phillips, Brammer, Bullmore, Williams, van Amelsvoort, Robertson, David & Murphy, 2000; Winston, O'Doherty & Dolan, 2003). Functional neuroimaging studies have demonstrated that the amygdala is disproportionately activated by fearful facial expressions (Breiter *et al.*, 1996; Morris, Frith, Perrett, Rowland, Young, Calder & Dolan, 1996; Whalen, Shin, McInerney, Fisher, Wright & Rauch, 2001). Bilateral amygdala damage consistently impairs the recognition of emotional facial expressions, especially for fear (Adolphs, Tranel, Damasio & Damasio, 1995; Anderson & Phelps, 2000; Calder, Young, Rowland, Perrett, Hodges & Etcoff, 1996), but also for other negative emotions such as anger, disgust, and sadness (Adolphs Tranel, Hammann, Young, Calder, Phelps, Anderson, Lee & Damasio, 1999; Graham, Devinsky & LaBar, 2007). While the amygdala is usually thought of as being specialized for fear, amygdala activation has been implicated in the processing of a number of emotional facial expressions (Fitzgerald, Angstadt, Jelsone, Nathan & Phan, 2006; Winston *et al.*, 2003). Processing and recognition of facial expressions also involves activation of the PFC (Nakamura, Kawashima, Ito, Sugiura, Kato, Nakamura, Hatano, Nagumo, Kubota, Fukuda & Kojima, 1999; Winston *et al.*, 2003), especially for angry expressions (Blair, Morris, Frith, Perrett & Dolan, 1999). PFC activity increases during state-induced anger (Harmon-Jones & Seligman, 2001) as well as self-induced anger (Kimbrell, George, Parekh, Ketter, Podell, Danielson, Repella, Benson, Willis, Hercovitch & Post, 1999). Additionally, electroencephalographic studies have repeatedly demonstrated increases in left PFC activity in people with high levels of trait-anger (see Harmon-Jones, 2003, for review). The anterior insula, which has connections with the PFC, autonomic system and limbic areas (Augustine, 1996; Carr, Iacoboni, Dubeau, Mazziotta & Lenzi, 2003) is implicated during the observation of angry faces and angry hand actions (Grosbras & Paus, 2006) as well as disgust faces (Phillips, Young, Senior, Brammer, Andres, Calder, Bullmore, Perrett, Rowland, Williams, Gray & David, 1997). While these regions show some emotion specificity, meta-analyses of neuroimaging studies suggest that emotion categories have distributed, overlapping representations in the brain (e.g. Phan, Wager, Taylor & Liberzon, 2002).

Neurodevelopmental studies suggest that the brain areas important for facial expression processing continue to develop structurally throughout late childhood and adolescence and show corresponding functional differences. The PFC is one of the latest areas of the brain to mature (Casey, Giedd & Thomas, 2000; Casey, Tottenham, Liston & Durston, 2005). The amygdala continues to develop throughout late childhood and adolescence (Giedd, Vaituzis, Hamburger, Lange, Rajapakse, Kaysen, King, Vauss & Rapoport, 1996; Schumann, Hamstra, Goodlin-Jones, Lotspeich, Kwon, Buonocore, Lammers, Reiss & Amaral, 2004; Thomas, Drevets, Whalen, Eccard, Dahl, Ryan & Casey, 2001), and there is also evidence that the fusiform gyrus does as well (Aylward, Park, Field, Parsons, Richards, Cramer & Meltzoff, 2005). Functional neuroimaging studies indicate that adolescents have different neuronal activation patterns to subsequently remembered emotional faces than adults (Nelson, McClure, Monk, Zarahn, Leibenluft, Pine & Ernst, 2003), including changes in the PFC and regions related to emotion such as the anterior cingulate cortex and temporal pole. Monk and colleagues (Monk, McClure, Nelson, Zarahn, Bilder, Leibenluft, Charney, Ernst & Pine, 2003) demonstrated greater orbital frontal cortex activation in adults relative to adolescents during viewing of fearful versus neutral faces. Children aged 4–15 also exhibit reduced effects of emotion on positive-going event-related potentials relative to adults (Batty & Taylor, 2006).

These anatomic and functional changes occurring in late childhood and adolescence are at odds with the behavioral literature and suggest that emotional facial recognition abilities may not reach maturity until adulthood. Emotions such as fear and anger, which rely on brain regions that continue to mature through adolescence, may show late developmental trajectories. Social emotions that rely on PFC maturation, including anger, may develop latest. Because late anatomic development may entail a fine-tuning of facial emotion recognition abilities, more sensitive behavioral tests are needed that do not rely on verbal labeling or perceptual matching to help characterize developmental changes in brain–behavior relations underlying facial affect perception.

Here we use a two-alternative forced-choice task with faces displaying morphed expressions to investigate the late

Table 1 *Demographics for children, adolescents and adult participants*

Group	FSIQ	VIQ	SES code	Ethnic composition
Children (n = 31)	116.64 ± 17.35	13.74 ± 5.2	3.90 ± 1.04	12 AA, 19 C
Adolescents (n = 23)	111.82 ± 16.04	12.35 ± 3.49	4.09 ± 0.79	6 AA, 16 C, 1 A
Adults (n = 48)	109.16 ± 18.31	58.24 ± 8.09	3.67 ± 1.15	11 AA, 19 C, 15 U

Notes: Means and standard deviations are shown for Full Scale IQ, Verbal IQ, and SES code.
IQ for children and adolescents measured with the Wechsler Intelligence Scale for Children (WISC-R).
IQ for the adults measured with the Wechsler Adult Intelligence Scale (WAIS-III).
SES code on a scale of 1–5, 1 being lowest SES, 5 being highest.
Ethnic composition abbreviations: African-Americans (AA), Caucasian (C), Asian (A), Unknown (U).

developmental trajectory of emotional face recognition. We examined fearful and angry face morphs, which are both negative and arousing stimuli (Adolphs *et al.*, 1999). Blends of fear and anger with neutral facial expressions examined sensitivity to changes in emotional intensity, whereas morphs of fear and anger expressions investigated sensitivity to emotion blends. Specifically, we examined the overall sensitivity of each group to the target emotion in each morph type, as well as their sensitivity to small changes in the intensity of the emotion for each morph type. We predicted that adults would show superior performance over both adolescents and children. In addition, because of the late maturation of PFC and its suggested role in anger processing, we predicted that anger morphs would exhibit a delayed developmental time course relative to fear morphs.

Method

Participants

Three groups of healthy participants were tested. The young participant group consisted of 31 children (18 female) aged 7–13 years (mean age = 10.4 years). The adolescent group consisted of 23 adolescents (nine female) aged 14–18 years (mean age = 15.7 years). The adults (N = 48, 41 female) ranged in age from 25 to 57 years (mean age = 39.2 years) and were parents of the participating children and adolescents. Although the age range of the adults spans from young to middle adulthood, the majority were in their 30s (N = 20) and 40s (N = 20). The Tanner stage of the children and adolescents was determined via questionnaire to measure development of secondary sex characteristics (Tanner & Davies, 1985). The mean ± SD Tanner stage for the children (1.9 ± 0.94), was significantly lower than for the adolescents (4.0 ± 0.87), $t(54) = 8.23$, $p < .0001$. All participants were recruited and examined at the Healthy Childhood Brain Developmental Traumatology Research Program in the Department of Psychiatry and Behavioral Sciences at Duke University Medical Center. Subjects were recruited by advertisement from the community after passing a 32-question medical and mental health questionnaire and extensive clinical evaluations. The Schedule for Affective Disorders and Schizophrenia for School Aged Children Present and Lifetime Version (Kaufman, Birmaher, Brent, Rao, Flynn, Moreci, Williamson & Ryan, 1997) ruled out the presence of a current and lifetime history of DSM-IV Axis I mental disorders. An abbreviated version of the Wechsler Intelligence Scale for Children (WISC-R) provided an estimate of intelligence for the children and adolescents (Wechsler, 1974). The Wechsler Adult Intelligence Scale (WAIS-III) was used to evaluate intelligence in adults (Wechsler, 1997). There were no IQ, socioeconomic status, or ethnicity differences across groups, although ethnicity was not ascertained for all participants in the adult sample (see Table 1). Socioeconomic status (SES) for each subject was completed using the Hollingshead Four Factor Index (Hollingshead, 1975). Exclusion criteria for children and adolescents were: (1) current or lifetime history of psychiatric disorders, including alcohol and substance use disorders, (2) a significant medical, neurological, or psychiatric disorder or history of head injury or loss of consciousness, (3) a history of prenatal confounds that may influence brain maturation such as prenatal exposure to illicit substances or pregnancy and birth complications, (4) severe obesity or growth failure, (5) full scale IQ lower than 80, (6) child maltreatment history. Adults were interviewed for the presence of DSM-IV current and lifetime major Axis I disorders using a Research Diagnostic Criteria checklist approach based on the Family Study Method (Andreasen, Rice, Endicott, Reich & Coryell, 1986). Those with a past or current history of a major DSM-IV Axis I mental disorder were excluded from this study. This study was approved by the Institutional Review Board of Duke University Medical Center. A complete description of the study was given to the subject and legal guardians, and written informed consent was obtained. Subjects received monetary compensation for participation.

Stimulus development

Emotional facial expressions of the emotions fear and anger were taken from the Ekman pictures of facial affect (Ekman & Friesen, 1976; Matsumoto & Ekman, 1988). All expressions were posed in full frontal orientations, so there were no changes in head orientation either across or within morphs. Faces were cropped with an ovoid mask to exclude extraneous cues such as hair, ears, and neckline. Images were normalized for contrast and luminance and presented against a gray background. Prototypical expressions of fear and anger were morphed together and with neutral expressions of the same actor to create the experimental stimuli. Three different morph progressions were used: neutral-to-anger, neutral-to-fear, and fear-to-anger. The Ekman face morphs used in this experiment were created in-house using the methods described in detail in LaBar, Crupain, Voyvodic and McCarthy (2003) using MorphMan 2000 software (STOIK, Moscow, Russia). It should be noted that angry facial expressions may either be demonstrated with teeth bared or not. Out of the 10 models used in the morph progressions, five angry faces were close-mouthed, and five had teeth showing; all models had furrowing of the brow and narrowed eyes, consistent with facial demonstrations of anger.

The endpoints of each morph increment were removed from the stimulus set to display only the intermediate expressions in each progression. Six morph increments were therefore used that encompassed the middle portion of the continuum from each source and target emotion. As an example, for the neutral-to-anger continuum, morph increment one was 77.77% neutral/22.22% angry, morph increment two was 66.66% neutral/33.33% angry, morph increment three was 55.55% neutral/44.44% angry, etc. A total of 180 images were used (3 emotion morph types × 10 models × 6 morph increments). One example from each of the three emotion continua are shown in Figure 1.

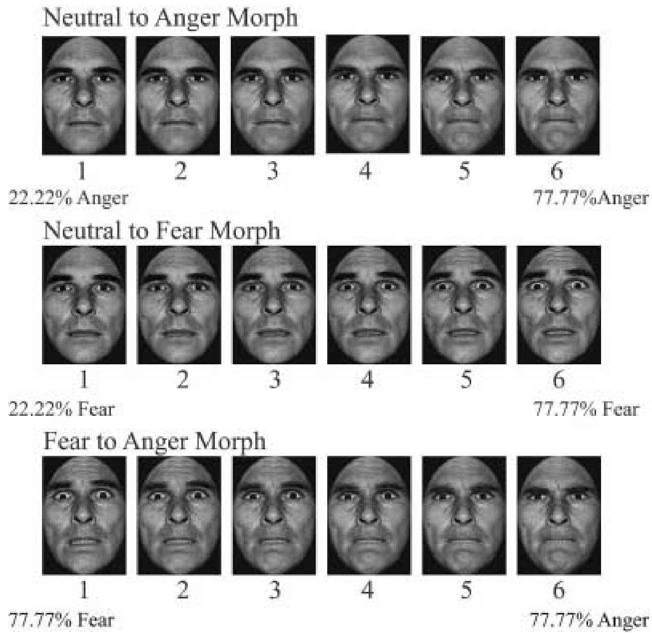

Figure 1 *Examples of the three emotion morph continua used in this experiment: A) neutral to anger, B) neutral to fear, and C) fear to anger.*

Design and procedure

The morphed faces were used in three, two-alternative forced-choice identification tasks, one for each emotional morph type (neutral-to-anger, neutral-to-fear, fear-to-anger). Each trial consisted of a fixation screen for 1000 ms (a scrambled face superimposed onto a central crosshair), followed by an individual emotion morph for 3000 ms. A response selection screen (two facial expression endpoint descriptors that differed for each of the three morph tasks) then appeared and was displayed until the participant made a response. Participants viewed the following instructions on the screen (e.g. for a neutral to anger block): 'In this task, you will see faces that depict different emotions. You will be asked to judge whether the face expresses a neutral emotion or anger. Please answer as quickly and accurately as possible using the following scale: Press button 1 if you think the face is emotionally neutral or button 2 if you think the face expresses anger. The rating scale will appear after each face so you will not have to remember it.' The duration of the stimuli was decided by a pilot study, which revealed that children needed about 3000 ms in order to make a response. Each of the three tasks was administered twice to each participant. Task order was counterbalanced across participants. There was no time limit for responding and no feedback was given.

Data analysis

Corrected d' scores for two-alternative forced-choice tasks (MacMillan & Creelman, 1991) were computed for each morph increment, which were incrementally summed to generate cumulative d' scores. The average d' and d' slope of the cumulative functions were computed for each participant in each group across each of the three morph types. Average d' represents the average sensitivity of participants to the presence of the target emotion over the six morph increments. The d' slope value is the slope of the d' values over the six morph increments, and indexes the sensitivity of the participant to small changes in facial expression across the morph increments.

For each morph progression, separate repeated-measures ANOVAs were computed for the average d' and the d' slope as dependent variables. For both ANOVAs, experimental group (children, adolescents or adults) served as the between-subjects variable. If the main effect of group was significant, Bonferroni-corrected pairwise t-test comparisons were conducted. In addition, two sets of correlations were calculated between the two sensitivity measures (average d' and cumulative d' slope) and age. The first set of correlations included all three age groups. To more finely examine the relationship between sensitivity to facial expression and developmental stage, the second set of correlations included only children and adolescents, comparing the sensitivity measures against age and Tanner score. To make inferences about speed–accuracy tradeoffs, an additional set of ANOVAs was run with median reaction time (RT) as the dependent variable for each morph type and age group as the between-subjects factor. Finally, to investigate potential differences in developmental time courses for the three morph types, trend analyses were computed using orthogonal polynomial contrasts on the average d' and cumulative d' slope measures.

Results

The raw identification results are summarized in Figure 2. Inspection of these graphs indicated that the recognition data from adults were qualitatively different from those of children and adolescents, and that the neutral-to-anger morph appears to have a different pattern than the neutral-to-fear and fear-to-anger morphs. To quantify differences in sensitivity across the three participant groups and morph types, the data were analyzed using signal detection methods to calculate average d' and d' slope.

Neutral-to-anger morphs

The sensitivity to the target emotion (anger) for each group in the neutral-to-anger morph is depicted in Figure 3A. The ANOVA for average d' revealed a main effect of group (Figure 3D), $F(2, 99) = 32.61$, $p < .0001$. Bonferroni-corrected post-hoc tests showed that adults had significantly higher average d' values than both children and adolescents (both ps $< .0001$), who did not differ from each other. The ANOVA for d' slope revealed a main effect of group (Figure 3G), $F(2, 99) = 20.48$, $p < .0001$. Bonferroni-corrected post-hoc tests showed that adults had significantly higher d' slope values than both children and adolescents (both ps $< .0001$), who did not differ from each other. Pearson correlations conducted across the entire sample showed a significant positive relation-

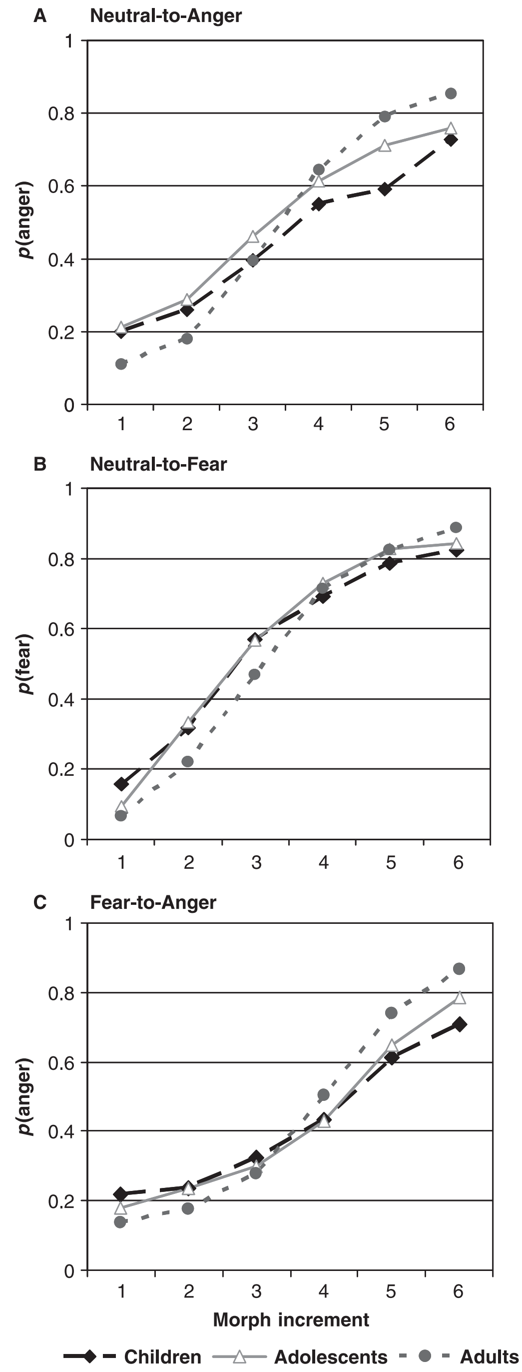

Figure 2 *Identification of emotion in morphed images for the three morph types by each participant group. The mean percentage of times that A) participants identified the faces in the neutral-to-anger continuum as angry, B) participants identified the faces in the neutral-to-fear continuum as fearful, and C) participants identified the faces in the fear-to-anger continuum as angry.*

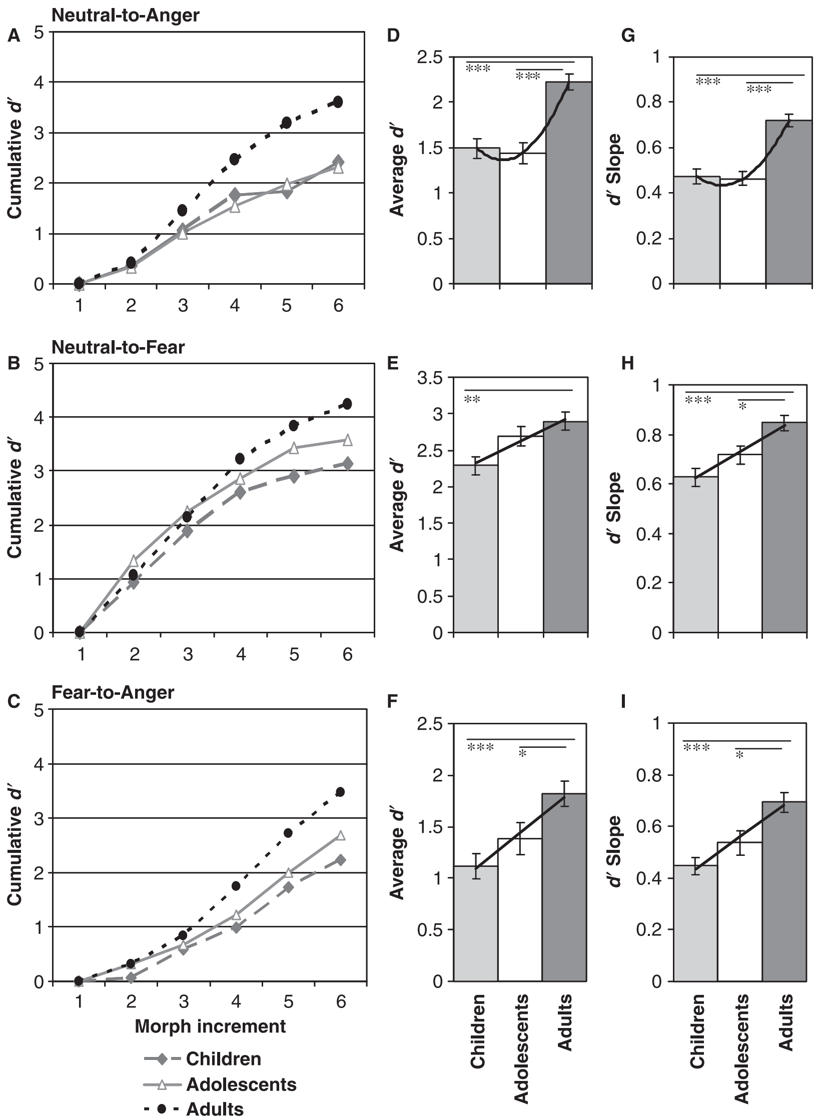

Figure 3 *Cumulative* d′ *functions and slope values of these functions for the three morph types, with trend lines. Cumulative* d′ *functions for A) the neutral-to-anger morph, B) the neutral-to-fear morph, and C) the fear-to-anger morph. The average* d′ *of these functions for D) the neutral-to-anger morph, E) the neutral-to-fear morph, and F) the fear-to-anger morph. The average* d′ *slope of these functions G) the neutral-to-anger morph, H) the neutral-to-fear morph, and I) the fear-to-anger morph. Asterisk (*) indicates* $p < .05$*, two asterisks (**) indicate* $p < .01$*, three asterisks (***) indicate* $p < .001$*.*

ship between age and average d' values ($r = .54$, $p < .0001$) and between age and d' slope values ($r = .6$, $p < .0001$). However, when the correlations were restricted to children and adolescents, no significant relationships were found between the two sensitivity measures and age or Tanner stage (all $rs \leq |.20|$, $p > .05$). Age-related differences in facial affect recognition on the neutral-to-anger morphs were due to greater sensitivity in adults relative to children and adolescents. Within the late-childhood and adolescent age groups, there were no significant differences between facial expression sensitivity and age.

Neutral-to-fear morphs

The sensitivity to the target emotion (fear) for each group in the neutral-to-fear morph is depicted in Figure 3B. The ANOVA for average d' revealed a main effect of group (Figure 3E), $F(2, 99) = 6.47$, $p < .002$. Bonferroni-corrected post-hoc comparisons showed that adults had significantly higher average d' values than children ($p < .002$), while adolescents did not significantly differ from the other groups. The ANOVA for d' slope revealed a main effect of group (Figure 3H), $F(2, 99) = 14.69$, $p < .0001$. Bonferroni-corrected post-hoc tests indicated that adults had significantly larger slope values than both children ($p < .0001$) and adolescents ($p < .05$), who did not differ from each other. Pearson correlations conducted across the entire sample showed a positive relationship between age and average d' values ($r = .3$, $p < .002$) as well as age and d' slope values ($r = .43$, $p < .0001$). However, when the correlations were restricted to children and adolescents, no significant relationships were found between the two sensitivity measures and age or Tanner stage (all rs $\leq |.20|$, $p > .05$). Age-related differences in facial affect recognition on the neutral-to-fear morphs were due to greater sensitivity in adults relative to children and adolescents. Within the late-childhood and adolescent age groups, there were no significant differences or relationships between facial expression sensitivity and age.

Fear-to-anger morphs

The sensitivity to the target emotion (anger) for each group in the fear-to-anger morph is depicted in Figure 3C. The ANOVA for average d' revealed a main effect of group (Figure 3F), $F(2, 99) = 8.66$, $p < .0001$. Bonferroni-corrected post-hoc tests indicated that adults had significantly higher average d' values than children ($p < .0001$), and adolescents ($p < .05$), while children and adolescents did not differ from each other. The ANOVA for d' slope revealed a main effect of group (Figure 3I), $F(2, 99) = 12.36$, $p < .0001$. Bonferroni-corrected post-hoc tests indicated that adults had significantly higher d' slope values than both children ($p < .0001$) and adolescents ($p < .02$), who did not differ from each other. Pearson correlations conducted across the entire sample showed a positive relationship between age and average d' values ($r = .33$, $p < .001$) as well as age and d' slope values ($r = .39$, $p < .0001$). When the correlations were restricted to children and adolescents, no significant relationships were found between the two sensitivity measures and age or Tanner stage (all rs $\leq |.1|$, $p > .05$). Age-related differences in facial affect recognition on the fear-to-anger morphs were due to greater sensitivity in adults relative to children and adolescents. Within the late-childhood and adolescent age groups, there were no significant differences or relationships between facial expression sensitivity and age.

Trend analysis

Although the ANOVA post-hoc tests indicated similar age effects across the three morph types, visual inspection of the graphs in Figure 3 suggests a more stepwise progression in sensitivity for both the neutral-to-fear morph and the fear-to-anger morph relative to the neutral-to-anger morph. To more carefully characterize differences in the developmental time course for the emotion morph types, trend analyses were conducted on the average d' and d' slope values across the entire sample. For the neutral-to-anger morph, a quadratic trend was significant for both average d' and d' slope (both ps $< .01$), which was driven by an asymmetric increase in sensitivity at the later end of the developmental spectrum (from adolescents to adults). For the neutral-to-fear and fear-to-anger morphs, only linear trends were found for both average d' and d' slope (all ps $< .001$). These results implicate a gradual developmental increase in fear recognition abilities (in faces that expressed both fear alone and fear blends) from childhood through adolescence to adulthood. In contrast, the ability to recognize anger intensity shows an abrupt developmental increase in sensitivity from adolescence to adulthood.

Reaction time (RT)

A main effect of group on RT was obtained for all three morph types (neutral-to-anger morph: $F(2, 99) = 17.88$, $p < .0001$; neutral-to-fear morph: $F(2, 99) = 9.59$, $p < .0001$; fear-to-anger morph: $F(2, 99) = 19.41$, $p < .0001$). In all cases, Bonferroni-corrected post-hoc tests showed that children were significantly slower than both adolescents and adults (all ps $< .02$), who did not differ from each other.

Gender

It has been suggested that females are better at identifying emotional facial expressions (Hall, 1978, 1984), as well as having different patterns of amygdala and prefrontal activation than males (Killgore & Yurgelun-Todd, 2001). There is also evidence suggesting differing patterns of development of these brain regions in males and females (Killgore, Oki & Yurgelun-Todd, 2001; Killgore & Yurgelun-Todd, 2004). These studies suggest that gender is an important issue to consider when measuring emotion recognition abilities. Because our group samples were imbalanced with respect to gender representation (with proportionally more females in the adult group), we conducted ANOVAs including gender and group as between-subjects factors and average d' and d' slope as dependent measures for all three morph types. We found a main effect of group on the average d' and d' slope on all three morph types (all Fs > 4.0). There were no main effects of gender on the average d' and d' slope on all three morph types (all Fs < 2.0). There were also no group × gender interactions on the average d' and d' slope on all three morph types (all Fs < 1.5).

General discussion

To characterize the late developmental trajectory of facial emotion recognition, the present study tested children, adolescents, and adults on two-alternative forced-choice tasks using morphed facial expressions. Data were analyzed using signal detection methods to characterize sensitivity to detect changes in emotional expression across three morph progressions: neutral-to-anger, neutral-to-fear, and fear-to-anger. Analysis of average sensitivity (d') in each morph progression indicated that adolescents and children showed equivalent performance, whereas adults showed greater sensitivity to the target emotion than both children and adolescents. Slope analysis supported the finding that adults were more sensitive to small changes in emotional facial expressions across the categorical boundaries of all three morph types relative to both children and adolescents, who did not differ from each other. Trend analysis revealed different developmental time courses for fear and anger: whereas sensitivity to fear intensity and fear blends increased linearly across the age ranges tested, sensitivity to anger showed a quadratic trend, which was due to a marked increase in sensitivity from adolescence to adulthood. The marked increase was not due to relative difficulty differences across the morph types, since the neutral-to-anger morph showed intermediate d' scores relative to the other morph types. RT analysis indicated prolonged decision-making for the children compared to adolescents and adults. However, this effect did not translate into a speed–accuracy trade-off, since sensitivity did not differ between children and adolescents. In summary, our results provide evidence that emotional face recognition continues to develop from late childhood through adulthood, at least for negative emotions.

These findings contradict prior research that had suggested relatively complete development of facial emotion processing abilities by childhood. The paradigm we used assessed overall sensitivity to emotional facial recognition as well as sensitivity to small changes in emotional expressions. Importantly, our paradigm did not rely on perceptual matching or verbal labeling of canonical displays, which may have obscured performance deficits in prior studies.

The present study focused on fear and anger perception because the brain regions involved in the processing of these emotions show late developmental changes. Our finding that children and adolescents were less sensitive to fear and anger compared to adults suggests that their neural underpinnings are not yet fully. Several studies have pointed to significant growth of the PFC throughout the adolescent period (Casey *et al.*, 2000; Giedd, Blumenthal, Jeffries, Castellanos, Liu, Zijdenbos, Paus, Evans & Rapoport, 1999; Sowell, Trauner, Gamst & Jernigan, 2002; Spear, 2000), including grey matter increases in the dorsolateral PFC that do not reach adult levels until their third decade (Giedd, 2004; Reiss, Abrams, Singer, Ross & Denckla, 1996). The amygdala also continues to develop throughout adolescence (Giedd *et al.*, 1996; Schumann *et al.*, 2004; Thomas *et al.*, 2001), with substantial age-related changes in amygdala volume between 7.5 and 18.5 years of age (Schumann *et al.*, 2004). The lack of a significant difference in sensitivity to facial expression in children versus adolescents could be attributed to the fact that the myelination and pruning of synapses that forms these prefrontal-limbic emotional neural networks during adolescence are not yet fully mature.

Given that our morph task is sensitive to amygdala damage in adults (Graham *et al.*, 2007), it is possible that the differences evidenced between adults and children and adolescents are attributable to maturation of the amygdala and its connections with the PFC (see Elzinga & Bremner, 2002). A study examining amygdala response to facial expressions in children and adults (Thomas *et al.*, 2001) showed that while adults had increased amygdala activation to fearful versus neutral faces, children showed equivalent amygdala activity to both neutral and fearful faces, suggesting that the amygdala's response is not yet fine-tuned to the same stimuli that provoke amygdala activation in adults. There is also evidence that specialization of fusiform gyrus activation increases from early to late-childhood (Aylward *et al.*, 2005). These regions are especially sensitive to fear in facial expressions (Vuilleumier, Armony, Driver & Dolan, 2003) and may underlie the behavioral patterns observed in the present study.

Our result that recognition of angry facial expressions develops later than recognition of fearful facial expressions fits with the neurological data that the PFC develops later than the amygdala. The late development of anger detection may relate to the well-characterized neural maturation of the PFC that continues through adolescence, with important behavioral implications for understanding the neural mechanisms of anger evaluation in adolescents.

While this is a biological account of our results, there are other reasons why sensitivity to anger may develop later than fear. Anger is generally believed to be a self-conscious and social emotion (Berkowitz, 1999). There are cultural guidelines for expressing anger, and children continue to learn these social rules and norms throughout adolescence. A study examining the development of display rules for anger in children showed that children's likelihood of expressing anger is influenced by social context, with children more likely to mask anger with teachers than with peers (Underwood, Coi & Herbsman, 1992). This same study reported developmental differences in anger expression, with younger children (8-year-olds) being more likely to display anger than the older children (10- and 12-year-olds), who were more likely to mask their anger. In addition, there is an abundance of data suggesting that certain kinds of appraisal or attributional beliefs can intensify or weaken the anger experience (see Berkowitz, 1990).

The expression of fear also develops and changes throughout childhood as the result of cognitive development and the ability to recognize and understand dangers in the environment (Ollendick & King, 1991). Interestingly, the number of fears children report show a decline with increasing age (see Craske, 1997, for review). However, fear is not usually understood to be a social emotion; it is based more on instinctual flight/fight reactions. Berkowitz (1990) suggests that a fear experience starts with a person's conscious or preconscious escape-associated reactions, whereas a person's anger experience starts with internal feelings/thoughts/memories that incite an anger response. This highlights the difference between these two negative emotions: fear is seen as an instinctual reaction to an external threatening stimulus, while anger is a more cognitively controlled and socially influenced emotion, which may explain its later developmental trajectory.

Further studies are needed to investigate how both environmental and biological factors influence emotional recognition development in adolescents. There are a number of emotional issues that emerge at different times in adolescence, with parental conflicts likely in young adolescents, mood disruptions in mid-adolescence, and risk behavior in late adolescence (Steinberg, 1988; Steinberg & Morris, 2001). Such conflict could be related in part to the fact that adolescents have not yet reached adult levels of sensitivity to subtle emotional cues and their blends, as demonstrated in the current study.

Limitations

We observed that children and adolescents were less sensitive compared to adults in their perception of fear and anger, with sensitivity to anger developing somewhat later than fear. However, more emotion blends should be tested to see if the results generalize to other emotions. Furthermore, our study used only adult faces. Perhaps sensitivity to age-appropriate faces would boost performance in children and adolescents, although we were careful to include only facial expressions in our stimulus set that are panculturally representative of the specific emotion categories (Ekman, 1972). It is possible that cognitive factors influenced performance on this task and partly accounted for the better performance in adults. To minimize cognitive and motoric load effects, we used a relatively simple two-alternative forced-choice task, the emotion label choices were displayed on each trial, speeded responses were not required, stimuli were presented for a relatively long duration (3000 ms), and the task length was reduced from our original study (Graham *et al.*, 2007) to accommodate the shorter attention spans of children. Future studies that examine the transition from late-adolescence to early-adulthood will help identify the maturational level when an adult level of sensitivity to emotional facial expressions is reached.

Conclusions

Insights into the late developmental trajectory of facial affect processing have implications for understanding how children and adults differ in their interpretation of emotional information in interpersonal exchanges and their ability to socially communicate internal states. The current results could be indicative of the late maturation of prefrontal-limbic cognitive and affective processes, and has implications for affective disorders, as it is believed that deficits in emotional face processing are a component of social dysfunction in mood disorders in adults (Rubinow & Post, 1992; Surguladze, Young, Senior, Brebion, Travis & Phillips, 2004), as well as adolescents and children (McClure, Pope, Hoberman, Pine & Liebenluft, 2003; Pine *et al.*, 2004). A greater understanding of the normal developmental path for facial emotion recognition could enhance our understanding and diagnosis of such emotional disorders.

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