Annotation: Development of facial expression recognition from childhood to adolescence: behavioural and neurological perspectives

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Background: Intact emotion processing is critical for normal emotional development. Recent advances in neuroimaging have facilitated the examination of brain development, and have allowed for the exploration of the relationships between the development of emotion processing abilities, and that of associated neural systems. **Methods:** A literature review was performed of published studies examining the development of emotion expression recognition in normal children and psychiatric populations, and of the development of neural systems important for emotion processing. **Results:** Few studies have explored the development of emotion expression recognition throughout childhood and adolescence. Behavioural studies suggest continued development throughout childhood and adolescence (reflected by accuracy scores and speed of processing), which varies according to the category of emotion displayed. Factors such as sex, socio-economic status, and verbal ability may also affect this development. Functional neuroimaging studies in adults highlight the role of the amygdala in emotion processing. Results of the few neuroimaging studies in children have focused on the role of the amygdala in the recognition of fearful expressions. Although results are inconsistent, they provide evidence throughout childhood and adolescence for the continued development of and sex differences in amygdalar function in response to fearful expressions. Studies exploring emotion expression recognition in psychiatric populations of children and adolescents suggest deficits that are specific to the type of disorder and to the emotion displayed. **Conclusions:** Results from behavioural and neuroimaging studies indicate continued development of emotion expression recognition and neural regions important for this process throughout childhood and adolescence. Methodological inconsistencies and disparate findings make any conclusion difficult, however. Further studies are required examining the relationship between the development of emotion expression recognition and that of underlying neural systems, in particular subcortical and prefrontal cortical structures. These will inform understanding of the neural bases of normal and abnormal emotional development, and aid the development of earlier interventions for children and adolescents with psychiatric disorders. **Keywords:** Emotion expression recognition, facial affect, normal development, amygdala, neural correlates, brain development, emotional development.

Emotion identification is crucial for subsequent social interaction and functioning. The ability to decode facial expressions is an important component of social interaction because of the significant role of facial information in the appropriate modification of social behaviours (Philippot & Feldman, 1990; Vicari, Snitzer Reilly, Pasqualetti, Vizzotto, & Caltagirone, 2000). Abnormalities in emotion expression recognition are associated with psychiatric disorders in adult (Green, Kern, Robertson, Sergi, & Kee, 2000; for review, see Phillips, Drevets, Rauch, & Lane, 2003b) and child populations (Blair, 2003). A greater understanding of the normal development of emotion expression recognition and neural systems associated with this would therefore facilitate earlier identification of and appropriate therapeutic intervention for emerging patterns of aberrant emotional behaviour.

Despite the importance of social interaction and emotional development for well-being throughout the lifespan, the development of these processes over the childhood period remains surprisingly under-examined. Much of the literature has focused predominantly on the infant and preschool period (Nelson, 1987; see McClure, 2000, for a list of studies; Walker-Andrews, 1997). Those studies that have explored normal social and emotional development in childhood have tended to focus on more narrow age ranges, such as the preschool period, or between the ages of 7 and 10 years. Very little is known about the continued development of emotion processing over the full childhood range into adolescence, linking development across these age ranges. Furthermore, different methodologies employed by the different studies make comparisons across findings and age groups very difficult (see Vicari et al., 2000; Gross & Ballif, 1991).

This review employed a novel approach in integrating findings from studies examining the normal development of emotion expression recognition and prefrontal and subcortical neural systems important for this process. The following were specific aims:

1. To provide an overview of the literature on the normal development of emotion processing in children by:

a. describing different components of emotion processing, and using this framework for discussing their behavioural and neural correlates;

b. focusing on studies examining the development of the ability to identify emotionally salient stimuli in children ranging from preschool to adolescence;

c. examining factors influencing the development of emotion processing and methodological limitations of existing studies that may limit the interpretation of current data (i.e., the effect of verbal ability, IQ, socio-economic group, and sex effects).

2. To highlight neural systems important for emotion processing by:

a. outlining current understanding of the nature of neural systems important for emotion processing;

b. discussing the role of the amygdala, the most well-studied structure associated with emotion processing, and particularly fear processing;

c. describing data from the few studies to date that have examined the development of the above neural systems;

d. interpreting the above findings within the context of the development of prefrontal cortical-subcortical functional relationships and associated changes in emotional behaviour.

3. To discuss the relationship between points 1 and 2 in order to explain the normal development of emotion identification, and sex differences thereof, within the context of our current understanding of the normal development of neural systems important for emotion processing.

4. To provide an overview of abnormalities in emotion processing, particularly the identification of emotional stimuli, which may be associated with developmental disorders.

1. Overview of the normal development of emotion processing

a. Components of emotion processing

To date, there has been no generally accepted theory of emotion processing, nor any generally accepted theoretical framework with which to understand the development of emotion processing and associated neural systems (McClure, 2000; Phillips, Drevets, Rauch, & Lane, 2003a). The processing of emotionally salient information comprises physiological experiential components, cognitive components, behavioural/expressive components, attitudinal components, and regulatory components (Brody, 1985). These varied perspectives make it particularly difficult to study the development of emotion processing abilities (Brody, 1985; Plutchnik, 1984). A review, however, by Phillips et al. (2003a) has amalgamated findings from animal, human lesion and human neuroimaging studies to construct a framework for

identifying the neural bases of normal (adult) human emotional behaviour. The authors highlighted three related processes important to understanding emotional experience: (1) the identification of emotionally salient cues, (2) the production of an affective state and emotional behaviour as a response to these cues, and (3) the regulation of the affective state and behaviour, possibly through the inhibition of processes (1) and (2). The intact functioning of these three processes enables the individual to behave appropriately within any given social context. This framework has not previously been used to examine emotion processing in children.

We will discuss the development of the first of these processes in this review, the identification of emotionally salient cues, since the majority of studies examining the development of emotion processing within healthy populations have focused on this first process (Blair, 2003; Calder, Lawrence, & Young, 2001; Phillips et al., 2003a). Emotional information can be obtained via a number of different domains, including semantic information, prosody, and nonverbal visual cues: body postures and facial expressions, and in most cases, a combination of all of these. Most studies have focused on the identification of facial expressions because of the difficulties in examining the development of emotional information presented via other domains due to confounding factors such as verbal ability.

In this critical review, we will employ this framework with which to understand emotion processing to examine the development of emotion processing and associated neural systems throughout childhood to adolescence. We will focus upon studies examining the development of the ability to identify facial expressions of emotion, and will then aim to bring together findings from these studies with those from research examining the development of neural systems important for this process.

b. Recognition of emotion expressions: behavioural studies

There is a large body of literature on emotion expression recognition in infancy, providing evidence of remarkable abilities at a very young age (Hiatt, Campos, & Emde, 1979; Trevarthen, 1985; for review, see Walker-Andrews, 1997). Children as young as a few months old have been shown to be able to discriminate happy and sad faces from surprised faces, and also to discriminate between different intensities (i.e., mild versus intense happy expressions) (see Nelson & De Haan, 1997 for a review of studies). Furthermore, there is evidence that the facial expressions of others may alter infants' behavioural responses (Sorce, Emde, Campos, & Klinnert, 1985; Serrano, Iglesias, & Loeches, 1995; Montague & Walker-Andrews, 2001). Some studies do indicate the importance of additional factors (i.e., inclusion of vocal information, or use of dynamic

faces) in infants' ability to recognise emotion expressions (Caron, Caron, & Myers, 1985; Caron, Caron, & MacLean, 1988). However, there are methodological problems in studies of infants, since it is necessary to use different dependent measures to assess emotion expression recognition (i.e., using habituation and preference) compared to studies with older children, making comparisons across development difficult (see McClure, 2000). These methodological discrepancies have led researchers to question whether the same construct of emotion expression recognition is being measured over development (when language is present or absent), and make it very difficult to discuss continuity of these functions over development (McClure, 2000). Rather than focusing on studies of infants, the aim of the current review is to draw upon the developmental trajectories of emotion expression recognition, spanning the preschool years and above.

Results of a number of studies on the development of emotion expression recognition (mainly those focusing on the preschool years) have reported that the recognition of emotional expressions improves with age (Boyatzis, Chazan, & Ting, 1993; Odom & Lemond, 1972; Philippot & Feldman, 1990). However, studies indicate that emotion expression recognition does not emerge as one specific stage in development (Camras & Allison, 1985; De Sonneville et al., 2002; Gross & Ballif, 1991; Smith & Walden, 1998; Vicari et al., 2000). Rather, children's abilities emerge gradually over time, with happiness recognised earliest and with the greatest accuracy, followed by sad or angry expressions, then by expressions of surprise or fear. Children have difficulty recognising neutral facial expressions (Gross & Ballif, 1991). It has also been shown that younger children rely on facial expressions for information on another's emotional state to a greater extent than situational cues. A study exploring facial expressions and situational cues of emotion demonstrated that children's reliance on situational cues increased with age (Hoffner & Badzinski, 1989). Three- to five-year-olds focused almost exclusively on facial expressions, whereas by eight or nine years of age, children relied additionally upon situational cues. Furthermore, with increasing age, children become more insightful into their own emotional lives, and demonstrate increased understanding of mixed emotions in others (Izard & Harris, 1995).

To our knowledge, no studies to date have examined in childhood the development of emotion expression recognition in people familiar compared with those unfamiliar to the child. We are aware only of studies exploring the effects of familiarity upon expression recognition in infancy (Kahana-Kalman & Walker-Andrews, 2001) or upon face identity recognition. Previous studies have focused on the effects of familiarity on face recognition (Carver et al., 2003; Chung & Thomson, 1995), but they have not investigated its effect on emotional recognition. We

would predict that to more familiar faces (e.g., that of a parent), younger children may demonstrate more accurate identification of facial expressions than previously reported, since most developmental studies have employed unfamiliar rather than familiar facial stimuli. Alternatively, it may not be the processing of the face per se, but, rather, younger children's reliance on external cues (i.e., hair, ears etc.) that may reduce attention to features changing within the face (Campbell, Walker, & Baron-Cohen, 1995). Previous research has indeed demonstrated that between the ages of 7–11 years, children begin to attend to inner rather than external facial features (Campbell et al., 1995; Want, Pascalis, Coleman, & Blades, 2003). To our knowledge, however, there has been no research examining the effect of face familiarity upon emotion expression recognition during childhood development. Further studies could employ techniques such as eye-tracking, which measures spatial and temporal features of visual attention, which will help to determine change over development in attention to inner versus outer features, and the relation between this and emotion expression recognition.

Methodological limitations of behavioural studies. Despite evidence for the continued development of emotion expression recognition over the childhood period, methodological limitations constrain conclusions. Many of these studies have focused upon the preschool period. Children's ability to recognise emotional expressions has been shown to improve with age, although the extent and range of this change has been unclear. Differences in the type of stimuli presented between studies can make interpretation of results difficult. A number of studies focusing on preschool development have employed schematic stimuli for exploring emotion expression recognition, which may prove to be oversimplistic (see Gross & Ballif, 1991 for a review), rather than more realistic stimuli that are well-validated representations of emotional expressions (i.e., Ekman & Friesen, 1976; Izard, 1971). Additionally, the majority of studies have utilised static rather than dynamic facial stimuli (i.e., animated stimuli depicting emerging facial expressions). The use of dynamic facial stimuli depicting changes in facial expressions over time may impact on the manner in which facial expressions are processed, and may also be associated with different underlying neural structures compared with static faces (Haxby, Hoffman, & Gobbini, 2000, 2002). De Sonneville et al. (2002) conducted one of the few studies to explore normal emotion expression recognition in children (7–10 years old) using realistic and dynamic stimuli. The use of dynamic stimuli may provide subtle indices of children's facial expression recognition development through the examination of factors such as speed of processing and errors. Results indicated that speed of processing (although not

necessarily accuracy) varied with emotion (fastest for happiness, slowest for fear), and that speed also increased with age, particularly for negative facial expressions. The use of such stimuli may be an important and more realistic method of examining the development of emotion expression recognition during childhood.

Furthermore, studies differ in the types of responses they require from participants (see Gross & Ballif, 1991 for a list of studies). Responses may rely differentially upon verbal ability, visuo-spatial skills, or other cognitive skills (Phan, Wager, Taylor, & Liberzon, 2002; Vicari et al., 2000). Many of the studies reviewed have focused upon accuracy scores as dependent variables in the examination of facial expression recognition. Very few studies have explored the development of children's speed in processing facial expressions. In the study of De Sonneville et al. (2002), the speed of processing was examined over childhood development. The authors noted that facial expressions may change very rapidly in a more realistic context and therefore may place greater demands on processing capacity. These authors highlighted that processing emotional expressions too slowly might seriously impede social communication and its development. Results indicated that speed of emotion expression recognition increased from 7 to 10 years of age, and that this improvement was especially evident for the more negative emotions. Furthermore, adult speed of processing was nearly twice as fast as that of children. These results highlight the importance of including a number of outcome variables, which may help to assess the development of more subtle skills in emotion processing. This will be particularly important for studying the continued development from childhood into adulthood.

Summary of behavioural studies. Overall, studies have demonstrated continued development of emotion expression recognition over development. Further subtleties may be assessed using more realistic stimuli and other outcome variables (such as speed of processing). However, much of the research has tended to focus on the younger age groups, and very little is known about the continued development of emotion expression recognition from childhood into adolescence and adulthood. It has been suggested that emotion expression recognition becomes gradually more accurate and faster through development, evident from studies on differential emotion expression recognition over time, faster processing with increased age, and a greater understanding of mixed emotions and gaining information about emotional states through facial expression and situational cues. The small number of studies examining these processing abilities throughout childhood and adolescence, and the methodological discrepancies apparent within existing studies outlined above, limit interpretations

about the development of emotion expression recognition. Further studies examining this continued development of emotion expression recognition over childhood and, in particular, the transition into adolescence, are therefore necessary in order to provide important data regarding aberrant patterns of emotion processing, and the association between these and prodromal symptoms of psychiatric disorders.

c. Influences on the development of emotion recognition

Additional factors may have a significant effect upon the development of emotion expression recognition. These factors include socio-economic status and verbal ability.

Socio-economic status. There is evidence that children from families of deprived socio-economic groups are significantly more at risk for emotional and behavioural difficulties in childhood (Caspi, Taylor, Moffitt, & Plomin, 2000; Goodyer, 2002). However, many of the studies conducted on emotion expression recognition have tended to include participants from upper and middle class backgrounds. Very few studies have explored the recognition of emotional expressions in samples of inner-city children. Smith and Walden (1998) investigated developing emotional expression recognition skills in Afro-American preschoolers, many of whom were from very socio-economically disadvantaged households. Results replicated those of previous studies (using Caucasian middle-class preschoolers) of a developmental trend in increased accuracy of recognition of emotional expressions over the preschool period. However, one difference did emerge with this sample of disadvantaged children. Findings indicated that they were more accurate in the recognition of fearful facial expressions. The authors suggested that these findings may have resulted from the exposure of the children in the study to high-stress living environments and neighbourhoods, where expressions of fear may have been especially salient signals and therefore important to recognise. Perhaps slightly discrepant with this finding was that overall, income was positively correlated with children's accuracy scores. It is possible that a more negative or threatening environment may serve to prime children towards the recognition of negative emotional expressions. Taken together, these results suggest that the environment in which children develop may bias children towards the identification of specific expressions (see also section 4). Future studies should take into account such factors when interpreting findings.

Verbal ability and IQ. The emergence of language makes it possible to identify a child's level of emotional understanding. Children start using

emotional words at approximately two to three years of age (Izard & Harris, 1995; Bretherton & Beeghly, 1982; Ridgeway, Waters, & Kuczaj, 1985). Throughout childhood, children's emotional vocabulary expands, which may aid children in the identification of more subtle expressions (Camras & Allison, 1985). The recognition of certain emotions, such as shame, embarrassment, and contempt, may emerge later and may also depend on cognitive development (Izard & Harris, 1995). Vicari et al. (2000) explored the development of emotion facial recognition in schoolchildren (5–10 years, 120 children). Results indicated that emotion recognition is a varied domain that develops differentially in relation to the area of cognition (i.e., visuo-spatial versus lexical semantic categories). However, to explore the development of lexical semantic categories, this study focused upon the use of verbal labels for emotional expressions within a story context and for photographs of facial expressions, and did not examine the identification of other emotionally salient stimuli (e.g., emotion words). To further explore the development of the recognition of different categories of emotional stimuli, i.e., visuo-spatial and lexical, it will be important to include additional emotionally-salient stimuli, in addition to emotional expressions. However, no studies to our knowledge have explored the relationship between verbal ability and emotion expression recognition from childhood into adolescence.

Verbal ability has been associated with IQ per se. Subtests assessing verbal ability in the Wechsler Intelligence Scale for Children Third Edition UK (WISC-III[uk]), such as the vocabulary and similarities subtests, have been noted to load most highly upon the overall verbal IQ score, and highly with the full IQ score (Kaufman, Kaufman, Balgopal, & McLean, 1996). Effects of IQ have also been found to be related to emotion expression recognition in children with Williams syndrome (Gagliardi et al., 2003). No studies to date to our knowledge have examined the relationship between the development of emotion expression recognition and IQ within the normal population. Measures of intelligence, such as IQ, may affect children's performance on emotion processing tasks via different routes. Intelligence may affect performance on a particular task, including the ability to attend to a number of stimuli. Furthermore, higher IQ and good verbal skills will impact on the ability to think abstractly, which may prove important for conceptualising emotions and feelings. Another important aspect of emotion processing may involve the association between experiencing an emotion and the memory of an emotionally salient event. The speed of establishing such an association may be influenced by intelligence. Furthermore, it remains unclear as to whether IQ has a significant effect upon accuracy of recognition of emotionally salient stimuli within the entire range of IQ, or only at the lower and/or higher ends of the spectrum. It is also unclear whether there is an effect of IQ upon the speed of emotion expression recognition, since few studies have employed this as the dependent variable. Further studies are clearly required in order to examine fully the potential effects of IQ upon emotional expression recognition throughout childhood and adolescence.

Sex effects. The conventional view is that females are more skilled in emotion processing. This would include aspects such as empathy, emotional understanding, and emotion expression recognition. In adults, there is evidence for this. A review by Hall (1978) indicated a female advantage for decoding nonverbal cues, with the strongest effect evident for the combination of verbal and auditory stimuli. This female advantage also held for the visual-only modality (i.e., facial expressions). The developmental literature on sex effects and emotion processing appears to be inconsistent (Brody, 1985), although it is probable that these inconsistencies arise out of methodological biases. For instance, a meta-analysis on sex and empathy in children and adolescence suggested that self-report methods of assessment might maximise these biases compared with observational methods of assessment (Eisenberg & Lennon, 1983). This, in conjunction with findings from the study of Vicari et al. (2000) demonstrating differential developmental pathways for lexical and visuo-spatial components of emotion expression recognition, highlights the importance of taking into account the task requirements in predicting sex differences.

McClure (2000) conducted a meta-analysis to examine sex differences in the development of facial expression recognition, and provided clear evidence for a small, although robust female advantage in emotion expression recognition over the developmental period (from infancy into adolescence). It is noteworthy that this sex effect is evident as early as infancy. McClure (2000) also noted that it is probable that the fact that a female advantage is evident so early suggests that other factors associated with being female play a role in the development of emotion expression recognition. These differences may potentially be related to the development of neural systems important for emotion processing.

It is also probable that display rules guiding the conditions appropriate for displaying emotions are taught differently to males and females. Socialisation practices and display rules may make it easier for girls to display emotion expressions. Blair (2003) suggested that different brain regions might affect the display of emotion, such that subcortical regions (mainly basal ganglia) may be necessary for spontaneous emotional displays, whereas cortical regions (i.e., frontal cortex) are involved in controlled emotional displays affected by display rules.

Summary. There is some evidence that certain factors such as sex, socio-economic status, and verbal ability may impact on developing emotion expression recognition. There appears to be a small, but robust female advantage in emotion expression recognition. The effects of certain environmental factors such as socio-economic status need to be further examined, but suggest some differences in emotion expression recognition specific to certain emotions (i.e., fear). Finally, verbal ability may play a role in developing emotion expression recognition. In future studies, however, there should be careful consideration of the choice of dependent variables and tasks, as these may involve different visuo-spatial and verbal processing demands.

2. Neural systems important for emotion processing

a. Neural systems for emotion processing

Recent methodological advances, particularly in functional neuroimaging techniques, have contributed to a deeper understanding of the development of neural systems important for emotion processing, and have led to further interest in studying brain and behavioural development. These advances have also been accompanied by an increasing interest in the development of the neural basis of social behaviour (Carver et al., 2003).

There is a wealth of literature examining the neural correlates of emotion processing in the normal adult brain. Most of these studies have employed facial expressions as emotional stimuli. Phan et al. (2002) conducted a meta-analysis of 55 Positron Emission Tomography (PET) and Magnetic Resonance Imaging (MRI) studies exploring neural regions activated by emotional stimuli. Results indicated that no specific brain region was consistently activated by all emotion tasks; however, the medial prefrontal cortex (MPFC) was activated by a number of different emotional stimuli, suggesting that it may have a general role in emotion processing. The anterior cingulate cortex (ACC) has also been implicated in emotion processing via its putative role in attention to emotionally relevant stimuli. This structure may also have a role in the regulation of emotion (see Phan et al., 2002; Phillips et al., 2003a).

Findings from animal, human lesion and neuroimaging studies consistently implicate specific neural regions in emotion processing. These regions were initially conceptualised as the 'limbic circuit' (Papez, 1937), and are now considered to include the following brain regions: rostral/pregenual anterior cingulate gyrus, ventromedial prefrontal (orbitofrontal) cortex, ventral striatum, ventral pallidum, substantia nigra, and the dorsomedial nucleus of the thalamus (e.g., Phillips et al., 2003a). More recently, Phillips et al. (2003a) have proposed the existence of two parallel neural systems of emotion processing: (1) a system comprising subcortical and ventral frontal cortical regions important for the identification of emotionally salient cues and the generation of emotional states, and (2) a system comprising dorsal frontal cortical regions important for the regulation of subsequent behaviour.

These neural regions may be activated to a differential extent depending on the emotion category presented, the process being assessed (i.e., emotional identification versus experiencing the emotion versus regulating emotional experience), and the cognitive demands of the task (Phan et al., 2002; Phillips et al., 2003a). Studies of emotion processing in adults have consistently highlighted the critical role of the amygdala and the ventral striatum (i.e., ventral putamen and caudate nucleus) in ascribing emotional significance to stimuli, particularly in the recognition of fearful facial expressions, and the role of the insula in the recognition of disgusted facial expressions (Breiter et al., 1996; Calder et al., 2001; Killgore, Oki, & Yurgelun-Todd, 2001; Killgore & Yurgelun-Todd, 2001; Morris et al., 1996; Phillips et al., 1997, 1998; Wright et al., 2001). Other studies have highlighted the role of the amygdala in response to sad facial expressions and also happy facial expressions (Blair, Morris, Frith, Perrett, & Dolan, 1999; Breiter et al., 1996; Schneider et al., 1997).

b. Role of the amygdala in emotion processing

The amygdala has consistently been associated with emotion processing (see Phan et al., 2002; Phillips et al., 2003a). Amygdalar activation has been identified in response to unfamiliar faces, eye gaze detection, facial expression presentations of fearful, sad, and happy expressions, fearful vocalisations, and in the enhanced perception of emotionally salient information (Davis & Whalen, 2001; Phillips et al., 2003a). The amygdala has been associated most consistently with the response to fearful stimuli, and during fear conditioning (see Phan et al., 2002 and Phillips et al., 2003a for review of studies). These findings relate to adult studies of emotion processing, and may not be applicable to emotion processing in childhood. A developmentally sensitive approach is therefore important. Assumptions regarding the nature of neural systems important for emotion processing based on adult models may be inappropriate for the examination of the neural basis of the development of emotion processing in children, in whom the organisation of neural systems per se may be significantly different from that of adults (Karmiloff-Smith, 1997).

c. The developing brain and neural systems for emotion processing

The advent of MRI has made it possible to explore structural and functional changes in the brain throughout development (Casey, Giedd, & Thomas,

2000). It has become possible not only to image the developing brain throughout childhood and adolescence but also to examine the relationship between developing neural correlates and emerging motor, cognitive, and social abilities (Durston et al., 2001). Despite the large body of literature examining the neural correlates of emotion processing in adults, very little research has been conducted on the development of these neuroanatomical structures, and the relationship between this and current understanding from behavioural studies of the development of emotion processing abilities per se. Structures that mediate emotion processing in adults may be different from those earlier in development (McClure, 2000). Research on the developing brain is only just emerging, along with the non-invasive techniques employed to study this development (Durston et al., 2001; Killgore et al., 2001; Thomas et al., 2001; Baird et al., 1999).

Before discussing the development of neural regions implicated in emotion processing, we will describe the current understanding of the nature of human brain development per se. Durston et al. (2001) presented a comprehensive review of MRI studies exploring normal brain development and developmental changes in relation to age and sex. Results indicated that total brain size does not increase beyond five years of age. However, white matter volume increases significantly from childhood to adulthood, whereas grey matter volume decreases over this period. This pattern of development was also demonstrated in a longitudinal MRI study of brain development in over one hundred participants aged between 4 and 21 years of age (Giedd et al., 1999). Interestingly, a different pattern of development occurred in the basal ganglia and temporal lobe structures (i.e., amygdala and hippocampus), according to sex and age. Whilst the caudate nucleus, global pallidus, and hippocampus were found to be disproportionately larger in female brains, the amygdala was found to be disproportionately smaller in female brains. Disorders that have been linked to basal ganglia functioning (which decrease in volume with age) appear to have an earlier onset (i.e., ADHD, Tourette's), and are also more common in boys. It is therefore possible that the relatively smaller size of the above basal ganglia structures predisposes boys to developing these disorders. Depression has been associated with smaller amygdala core nuclei volumes (Sheline, Gado, & Price, 1998; Sheline, Sanghavi, Mintun, & Gado, 1999). Higher rates of depression have been reported in women in epidemiological studies of adult (see Kessler, 2003) and children/adolescents (Cohen et al., 1993). However, there are discrepancies in the literature linking amygdalar volume and depression in children, since larger amygdalar volumes are associated with depression in paediatric populations (MacMillan et al., 2003). This requires further examination. Durston et al. (2001) also noted that the male brain is

approximately 10% larger than that of the female, with the relative sizes of most structures reflecting this. Stuss (1992) reviewed the literature on the biological and psychological maturation of the frontal lobes, and concluded that much of the biological maturation is completed by puberty, although there is evidence of continuing development into later years. The variation in size of different neural regions between males and females and over development can inform our understanding of the nature of the development of emotion expression recognition per se, and have implications for our understanding of developing psychopathology and the differential vulnerability to psychiatric disorders in males and females.

Structural and functional development of the amygdala. Evidence for the critical role of the amygdala in emotion processing has been described above. Despite the importance of the amygdala for emotion processing, the development of amygdala function has not been examined extensively. The role of the amygdala in emotion processing throughout childhood and adolescence remains unclear. Only a small number of studies have explored the development of the amygdala, and these have examined predominantly the nature of the amygdalar response to fearful facial expressions (Baird et al., 1999; Killgore et al., 2001; Thomas et al., 2001). Baird et al. (1999) demonstrated amygdalar activation to fearful faces in 12–17-year-olds. No effects of age or sex were reported. Only fearful facial expressions were employed in the study, in addition to a fixation cross baseline and nonsense, non-facial stimuli, with no other emotional expressions or neutral faces presented. Furthermore, only 12–17-year-olds were included, with no clear indication of how age effects were explored.

Thomas et al. (2001) addressed some of these issues by studying amygdalar activation to fearful facial expressions in two groups: a group of children (mean age 11 years) and adults. Adults demonstrated greater amygdalar activation to fearful facial expressions, whereas children showed greater amygdalar activation to neutral faces. The authors argued that the children might have detected the neutral faces as more ambiguous than the fearful facial expressions, with resulting increases in amygdalar activation to the former rather than the latter stimuli. Killgore et al. (2001) studied developmental changes in neural responses to fearful faces in children and adolescents. Results indicated sex-differences in amygdalar development: although the left amygdala responded to fearful facial expressions in all children, left amygdalar activity decreased over the adolescent period in females but not in males. Females also demonstrated greater activation of the dorsolateral prefrontal cortex over this period, whereas males demonstrated the opposite pattern. In another study, greater lateralisation of amygdalar activity (left amygdala) has been reported in adult males than females whilst viewing happy and fearful

faces, although both sexes demonstrated greater left amygdalar activation for fearful faces (Killgore & Yurgelun-Todd, 2001). Killgore et al. (2001) interpreted these findings as evidence for an association between cerebral maturation and increased regulation of emotional behaviour; the latter mediated by prefrontal cortical systems. It is possible that the pattern of decreased amygdalar and increased dorsolateral prefrontal activation in girls with increasing age reflects an increased ability to contextualise and regulate emotional experiences per se.

Limitations of neuroanatomical studies. It is difficult from these results to delineate a clear pattern of amygdalar development, although findings suggest sex differences, mainly relating to decreases in amygdalar activity with repeated stimulus presentation. The above studies represent very good attempts at investigating an under-studied area of research. However, there are a few weaknesses that may compromise the interpretation of the findings. Further studies are clearly required to clarify the effects of development and sex upon amygdalar responses to fearful and other facial expressions, taking into account the following limitations.

Firstly, some of the studies outlined have not included an adult control group (Baird et al., 1999; Killgore et al., 2001). Killgore et al. (2001) highlighted the importance of including an adult control group, so that the development of neural substrates underlying emotion expression recognition can be examined beyond adolescence. Thomas et al. (2001) did include an adult comparison group, although there were no females in this comparison group to adequately investigate sex-specific developmental changes.

Secondly, many of the fMRI studies of the development of the amygdala in response to fearful expression recognition have utilised a block design approach. This involves a number of trials of one type (i.e., fearful facial stimuli) being presented in a block, followed by a block of control trials. Killgore et al. (2001) noted that such a design might lead to attenuation or habituation of the amygdalar response to fearful and, indeed, other facial expressions. An 'event-related' design, in which both the stimuli of interest and the control stimuli in addition to a baseline are presented within the same experiment but in an unpredictable, pseudorandom manner, may help to reduce habituation effects, allow for a shorter task (which is important when scanning children), and enable the presentation of both emotional and control stimuli within the same task. Previous studies have also indicated greater habituation of the left compared with the right amygdala in adults (e.g., Phillips et al., 2001; Wright et al., 2001). An event-related design may therefore help in the study of the nature of the habituation of right and left amygdalar responses over development and sex differences associated with this.

Thirdly, some of these studies have not used appropriate control tasks (i.e., Baird et al., 1999). Results from adult studies suggest that the most appropriate control stimuli for exploring amygdalar responses to fearful faces are neutral facial expressions, which control for the effects of face processing per se, and thereby allow the measurement of neural responses to the emotional component of the facial expression (e.g., Phillips et al., 1997). The limited data to date available from studies in children suggest that this type of experimental paradigm may not be appropriate for children, however. For instance, in the study by Thomas et al. (2001), a greater amygdalar response to neutral than to fearful facial expressions was demonstrated by children, whereas adults demonstrated a greater amygdalar response to fearful expressions. There therefore needs to be further consideration of appropriate control stimuli in neuroimaging studies of facial expression recognition in children. One possibility would be to include a non-face baseline, in addition to neutral and fearful facial expressions.

Finally, the effect of development upon neural responses to different facial expressions should be examined. Neuroimaging studies of emotional expression recognition have focused predominantly upon neural responses to one specific emotion: mainly fear in child and adolescent studies and the associated amygdalar response. To date, studies have also focused on examination of the development of the amygdalar response to emotional expressions, rather than that of other neural regions (i.e., the insula and ventral striatum) in response to these stimuli.

d. Development of prefrontal cortical and subcortical functional relationships

The functional relationships between subcortical and prefrontal cortical regions in the response to emotionally salient stimuli have, to date, been relatively under-examined. This may be crucial for increasing understanding of the development of emotion expression recognition. White matter volume increases significantly with age, whereas grey matter volume decreases with age (Durston et al., 2001). This impacts on the functional relationships between cortical and subcortical structures. Within the first two years of life, there is a large increase in myelination, improving the efficiency of the cortical and subcortical pathways (Herschkowitz, 2000). Axons constituting fibre pathways continue to develop into adolescence (Paus et al., 1999). Herschkowitz (2000) noted that the structural connections between the amygdala and the cerebral cortex become more streamlined around 10 months old with the myelination of the capsula interna, linking the two areas. This author also highlighted how the connections between the amygdala and the developing hippocampus (with its role in memory)

help to explain the emergence of the amygdalar response to fearful stimuli. These findings, taken together with the knowledge that the prefrontal cortex continues to develop into adolescence (Stuss, 1992), suggest that the functional connections between subcortical and prefrontal cortical regions may continue to develop into childhood and adolescence.

Results of a study exploring the cortical systems important for the recognition of emotional expressions in brain-damaged and control (adult) participants have yielded interesting inferences about the developmental significance of the amygdala (Adolphs, Damasio, Tranel, & Damasio, 1996). The findings of this study, in conjunction with those of previous studies (Adolphs, Tranel, Damasio, & Damasio, 1994, 1995; Hamann et al., 1996), indicated that the timing of amygdala damage impacts on the subsequent ability to recognise emotion expressions. For example, a subject with early bilateral amygdala damage was impaired in recognising facial expressions of fear, whereas two subjects who sustained bilateral amygdala damage in adulthood were not impaired in fear recognition. Adolphs et al. (1996) concluded that the association between the recognition of fearful facial expressions and the knowledge of the meaning of fear is acquired over development. The authors also concluded from these and previous findings that the amygdala is crucial during development for establishing the networks necessary for emotion expression recognition. However, once these networks are established they may function independently of the amygdala.

Perhaps some of the discrepant findings in the developmental studies of amygdala activation to fearful faces can be partially explained by these developmental changes in the functional relationships. With age, there is increased prefrontal and decreased subcortical activity. This may perhaps render older individuals less liable to enter into emotional states in response to facial expressions in others, because of a top-down inhibition of a subcortical response (Phillips et al., 2003a), although this may not necessarily affect the ability to initially identify the expression. As indicated above, it is also possible that the cortical–subcortical interactions are less well developed in younger children (i.e., as indicated with the females in the Killgore et al., 2001 study). This may also lead to a relative disinhibition of amygdalar activity to non-emotional expressions. Furthermore, early in development, children have been shown to have difficulty labelling neutral faces, and may detect these faces as particularly ambiguous, and therefore highly emotionally salient. For this reason, the amygdala may be activated to neutral faces to a greater extent than fearful faces (Thomas et al., 2001). It is perhaps the functional relationship between the amygdala and prefrontal cortical areas that ascribe meaning to the emotional stimuli, and help to explain developmental changes over the childhood years. Once amygdalar function

is fully developed, it is possible that it is the continued development of white matter tracts between this structure and prefrontal cortical regions that provides subsequent meaning and context to the emotional experience.

Summary of development of neural responses to emotional expressions. Studies of the neural correlates of emotion expression recognition highlight the role of the amygdala in the response to emotion expressions in both children and adults. There appears to be a developmental change in the function of the amygdala, however, such that adults demonstrate amygdalar activation in response to fearful facial expressions, whereas children demonstrate greater amygdalar activation to neutral faces (Thomas et al., 2001). There also appear to be sex-related differences in amygdalar function, particularly with regard to lateralisation of function and patterns of prefrontal cortical–amygdalar activity over development (Killgore et al., 2001; Killgore & Yurgelun-Todd, 2001). It is clear, therefore, that further investigation is required of the nature of the development of amygdalar structure and function, and the development of cortical-subcortical structural and functional connectivity, over childhood and adolescence.

3. Association between developing behavioural and neural systems of emotion processing

Clearly, there is a need for further examination of the development of the ability to identify different emotional expressions and the underlying neural systems. Findings to date indicate that further understanding of the development of the functional relationships between cortical and subcortical regions important for the response to emotionally salient stimuli may facilitate understanding of emotional behavioural development. It is also necessary to consider the specific demands of the task employed in response to emotionally salient stimuli, as these will invariably impact on patterns of neural response to the stimuli (e.g., Lange et al., 2003; Phan et al., 2002). For tasks requiring greater attentional demands, frontal cortical regions may be recruited to an increasingly greater extent, and subcortical regions to a decreasing extent.

Herschkowitz (2000) reviewed the neurological bases of behavioural development in the first two years of life and highlighted the importance of critical changes in development of specific structures and their structural associations with cortical regions in facilitating understanding of the subsequent changes in behaviour. The finding that the timing of amygdala damage can impact on subsequent emotion processing (see Adolphs et al., 1996) suggests that once certain neural systems are established,

potentially involving prefrontal cortical–subcortical connections, processing may continue despite damage to otherwise critical subcortical structures. With increasing age, these neural systems may become increasingly more important than specific neural regions per se. Given these findings, we might speculate that age-related improvements in emotion expression recognition and attention to situational cues when identifying these stimuli (Hoffner & Badzinski, 1989) may depend increasingly upon the integrity of structural and functional connections between cortical and subcortical structures. Increased efficiency of connectivity between cortical and subcortical structures may play an important role in the inhibitory control of emotion processing (Hariri, Bookheimer, & Mazziotta, 2000), and regulation of emotion processing per se (Phillips et al., 2003a). Further understanding of the functional relationships between prefrontal cortical and subcortical regions, and the development thereof, will help to clarify the nature of the development of emotion expression recognition, attention to contextual and situational cues, and associated emotional behaviour throughout childhood and adolescence.

4. Abnormalities in emotion processing

A failure to recognise or identify facial expressions of emotion can have wide-reaching and long-term detrimental effects upon social behaviour, and may serve as a risk factor for maladjustment and later adverse outcomes (Izard, 1977). For example, social problems in childhood have extensive implications for social and emotional adjustment in adulthood (Parker & Asher, 1987). Additionally, a core component of many psychiatric illnesses is poor social functioning, which would appear to be associated with impaired or inappropriate regulation of emotional behaviour. Different child and adolescent clinical populations have been shown to have deficits in facial expression recognition (Celani, Battacchi, & Arcidiancona, 1999; Dyck, Ferguson, & Shochet, 2001; Hobson, Ousten, & Lee, 1988, 1989; Pollack & Kistler, 2002; Stevens, Charman, & Blair, 2001; Walker, 1981).

The symptoms and severity of different psychiatric disorders may relate differentially to the various processes and underlying neural systems associated with emotion processing per se (see Phillips et al., 2003a, 2003b). Phillips et al. (2003b) propose that specific patterns of structural and functional abnormalities in parallel neural systems important for the response to emotional stimuli and regulation of emotional behaviour may be associated with the generation of different symptoms of psychiatric disorders, including schizophrenia, bipolar and major depressive disorder.

Perhaps the most widely studied area in terms of developmental psychopathology and emotional deficits is that of autism. Numerous studies have highlighted deficits in emotional functioning and the ability to recognise the emotional expressions of others in children with autism (Celani et al., 1999; Dyck et al., 2001; Hobson et al., 1988, 1989). However, there are contradictory findings from other studies. Adolphs, Sears, and Piven (2001) studied social information processing from faces in eight high-functioning adults with autism. Results indicated that participants with autism did not have any visuo-perceptual impairments in processing faces, nor any deficits in discriminating faces on the basis of the intensity of the emotion expression. Blair (2003), in a review, noted that once groups were matched on mental age, impairments on emotion expression recognition disappeared. He further noted that more complex cognitive emotions (i.e., embarrassment) yielded the most pronounced deficits in emotion expression recognition. A similar finding, highlighting the importance of controlling for mental age, was found by Gagliardi et al. (2003) using dynamic stimuli to explore emotion expression recognition in children with Williams syndrome compared with normal controls. Results indicated that children with Williams syndrome performed worse on the test of emotion expression recognition compared to age-matched controls, but performance was no different from mental age-matched controls. Rather than similarities in performance between Williams Syndrome participants and mental-age-matched controls relating to their use of similar processing strategies (i.e., younger children using a piecemeal method of recognising faces, and older children using a configural strategy), it is more likely that performance on the task relates to IQ. The authors suggest that higher IQ may reflect a better preservation of configural processing ability.

Walker (1981) examined emotion expression recognition in other childhood psychiatric populations. Children with schizophrenia were less accurate than aggressive, anxious-depressed, and normal children in recognising emotional expressions.

More specific deficits in emotion expression recognition have been reported in other child psychiatric groups. For instance, it has been shown that physically abused children label expressions of anger more frequently compared to non-abused children (Pollack & Kistler, 2002). Findings regarding recognition of emotional expressions in antisocial children have been inconsistent, however. Some studies have shown that the ability of these children to recognise emotional expressions displayed by others is not related to their externalising symptoms (Egan, Brown, Goonan, Goonan, & Celano, 1998; Walker, 1981). Other studies have highlighted the core component of psychopathic tendencies rather than general aggression as important for emotion processing deficits (see Blair, 2003). Stevens et al. (2001) found that children with more specific

psychopathic tendencies have deficits in recognising emotional expressions of sadness and fear, but not happy or angry expressions (Stevens et al., 2001). This may be associated with deficits in prefrontal cortical structures, including the orbito-frontal cortex (Blair, 2003).

Variations in brain development in relation to sex may have important implications for varying vulnerability to neuropsychiatric disorders. Durston et al. (2001) highlighted that the caudate nucleus, which is smaller in male brains, has been implicated in ADHD and Tourette's syndrome, disorders that are more prevalent amongst males. The amygdala, which is smaller in female brains, has been linked to affective disorders (i.e., anxiety and depression), disorders that are more prevalent amongst females. Furthermore, whilst there are many structural and functional connections between the basal ganglia and prefrontal cortex in the normal brain, findings from neuroimaging studies of children with ADHD have demonstrated decreased prefrontal cortical activity in this population (see Durston et al., 2001). Hypofrontality or decreased prefrontal activity in adolescents with ADHD has also been reported during cognitive tasks assessing executive functioning (Rubia et al., 1999, 2000).

Further research is required to clarify the extent to which deficits in emotion expression recognition are associated with symptoms of the different childhood and adolescent psychiatric disorders. Future studies should examine the neural correlates of emotion expression recognition abnormalities associated with these disorders. It may prove useful to examine the symptoms of childhood disorder within the context of the neuroanatomical framework proposed by Phillips et al. (2003b) to help understand the neural bases of some of the symptoms of psychiatric disorders in adults.

Conclusion

This review has aimed to bring together findings from studies examining the development in childhood and adolescence of the recognition of emotional expressions, an important component of emotion processing, and from those examining the nature of those neural systems important for emotion processing per se. Overall, results indicate a continued development of the recognition of emotional expressions into adolescence and early adulthood, particularly of the more subtle aspects of this process, including speed of processing. This development may be mediated by factors such as sex, socio-economic status, and verbal ability. Findings also suggest a continued development of function of neural regions underlying emotion processing. There is little research examining the continued development of emotion expression recognition from childhood into adolescence, however. Furthermore, studies examining the neural

correlates of emotion processing in children and adolescents have tended to focus mainly upon the response to fearful facial expressions and amygdalar development. Little is understood about the functional development throughout childhood and adolescence of neural systems important for the response to displays of other emotions. Evidence to date from studies of emerging emotion processing skills and aberrant patterns of development suggests distinct developmental trajectories for the recognition of different emotional expressions. Greater understanding of the development of neural regions and systems important for emotion processing, and, in particular, the development of subcortical–cortical structural and functional connections, may be an important focus for future research.

A greater understanding of the development of emotion expression recognition, a core social function, will provide valuable normative data that will inform the subsequent identification of abnormal patterns of emotional development. Examination of the development of emotion expression recognition, together with that of the neural systems important for these processes, will increase understanding of the specific abnormalities in these systems, which may be associated with the symptoms of psychiatric disorders. Furthermore, future studies will need to consider confounding factors and sex differences using standardised tests of emotion expression recognition across a wider age range. This will not only contribute to a greater understanding of the neural bases of normal and abnormal social development, but will also facilitate the development of earlier treatments for children and adolescents with psychiatric disorders.

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