Development of emotion recognition: Role of hemispheric laterality for processing facial expressions of emotion

Nikoleta Damaskinou

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Abstract

This thesis explores 5 to 12-year-olds recognition of facial emotion expression. The primary aim was to explore the electrophysiological patterns of activation in children and to assess the relationship of the development of hemispheric asymmetry for emotion processing with the development of different facial emotion recognition skills. These aims were examined in four studies, two of which used an EEG paradigm, and two of which were behavioural studies (one longitudinal and one cross-sectional). There were four key findings in this investigation:1) The CFT is an explicit test of laterality; 2) development differences in ERP activation for standard facial emotion showed a reduction of amplitudes with increasing age and that laterality patterns differed between the children in middle childhood, children in late childhood, and adults; 3) children's facial emotion recognition development varies depending on the emotion, the intensity, and task; 4) there is an association between the development of laterality and children's developing ability to accurately match facial expressions. These four primary findings were discussed with reference to our current understanding regarding the development of facial emotion recognition skills and the underlying neuropsychological development.

Author's declaration

This thesis is submitted for examination to the Royal Holloway, University of London for the degree of Doctor of Philosophy in Psychology. It has not been presented to any other university for examination either in the United Kingdom or overseas. I declare that this thesis is my own work and was carried out in accordance with the regulations of the University of London.

Signed: Nikoleta Damaskinou

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“Εὐλογητὸς Κύριος, ὅστις καθ' ἡμέραν ἐπιφορτίζεις ἡμᾶς ἀγαθά,
ὁ Θεὸς τῆς σωτηρίας ἡμῶν.”

Psalm 68: 1

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Chapter 1: Literature Review

1.1 Introduction

Facial expressions are a salient part of emotional behaviour and are a powerful tool in social interactions, as they allow the rapid communication of emotional states between individuals. Darwin (1872) was one of the first to acknowledge that people differentiate emotion expressions. In his book Expressions of the Emotions in Man and Animals proposed that the facial expressions are important for our welfare. They are means for a mother to communicate approval or disapproval to the child and encourages the child to modify their behaviour. Darwin also wrote that through facial expressions "We readily perceive sympathy in others by their expression; our suffering are thus mitigated, our pleasures increased, and mutual good feelings strengthened" (pp.170-171).

The ability, therefore, to accurately identify emotions from facial expressions is a crucial skill of emotion processing in everyday life: it can successfully guide individuals through social interactions (Watling, Workman & Bourne, 2012). More specifically, humans from facial expressions infer the attitudes and/or feelings of others (Cunningham & Odom, 1986) and these inferences guide their behaviour within interactions with others (Gao & Maurer, 2009; Johnston et al., 2011). Further, accuracy in recognition of emotions from faces is critical in the development of social competence and successful social interactions (Herba & Phillips, 2004). In fact, impairment in emotion expression recognition can have severe consequences and is associated with psychiatric disorders in adults and children. For instance, individuals with the developmental disorder of psychopathy and individuals with acquired sociopathy after lesions of the orbital frontal cortex do not respond appropriately to specific expressions. More specifically, psychopaths have the processing of sadness and fear particularly affected which results in a failure in socialization. In fact the psychopathic individual never learns to avoid actions that cause harm to others. In acquired sociopathy, individuals fail to adequately modify their behaviour according to the social context because the processing of others' anger is particularly affected (Blair, 2003). Impaired facial expression recognition (especially happiness) has been associated with major depression (Surguladze et al., 2004, 2005).

Given the importance of the ability to recognise emotions, this thesis focuses on how children process emotions. Emotional processing is conceptualized as three related processes, those being: the identification of emotional information; the production of emotional behaviour; and the regulation of emotion (Herba & Phillips, 2004). More specifically, the studies are designed to explore how developmental trends in children's strength of lateralisation for emotion processing are related to developments in facial emotion recognition ability.

Theoretical accounts of emotion recognition

How children process emotions in the brain is a key area of investigation for researchers (e.g. Batty & Taylor, 2006; Bava, Ballantyne, May, & Trauner, 2005; Chiang, Ballantyne, & Trauner, 2000). Evolutionary theories are often referred to when considering the importance of processing facial expressions of emotion, and highlight the importance of biology as opposed to experience. A growing evolutionary perspective of emotion suggests that the ability to recognise nonverbal facial expressions of emotion is important to recognise and communicate survival needs (Johnston, Kaufman, Bajic, Sercombe, Michie, & Karayanidis, 2011). Darwin (1872) suggested that all cultures share a discrete number of facial expressions and they recognise the meaning of these expressions. Ekman and Friesen (1972) supported Darwin when they showed that six universal “basic” facial expressions exist (happiness, sadness, anger, fear, surprise and disgust). The evidence that each of the six “basic” emotions are linked with distinct, universally recognised nonverbal expressions, supports this survival function of facial expression (Ekman, 1972, 2003; Tracy & Robins, 2008).

An evolutionary view of emotion expressions similarly assumes that the ability to recognise expression serves also an evolutionary adaptation: By means of rapid and efficient detection of emotional signals, humans become aware of a contextual situation and prepare rapidly an appropriate response (Ohman, 2000). To this direction, expressions, especially those that signal threat (e.g., fearful faces), trigger automatically and quickly the perceptual processing attentively or pre-attentively (Dolan, 2002; Tracy & Robins, 2008). Fearful faces for example, have been seen as aversive stimuli that rapidly communicate information to others that a stimulus is aversive and should be avoided (Mineka & Cook 1993). Similarly, sad facial expressions are also seen as aversive stimuli which discourage actions that caused sadness in another individual (Blair, 1995). Happy expressions, in contrast, are positive stimuli which increase the probability of occurrence of actions which appear to cause them (Matthews & Wells, 1999). Angry expressions serve to inform the observer to stop the current behavioural action which violates social rules or expectations (Blair, 2003; Blair & Cipolotti, 2000; Blair, Morris, Frith, Perrett, & Dolan, 1999).

Further to the evolutionary theories, researchers have focused on how biological and social factors may influence children’s emotion recognition skills development. While the ability to quickly and accurately interpret the emotional signals from others’ faces is a core component of social cognition (Johnston et al., 2011), more broadly speaking it is considered a “cornerstone” of children’s development (Levesque et al., 2003). Research investigating children’s developing facial emotion recognition skills typically explains this development through two different influences: social factors and maturation of the brain. Firstly, individual differences in social experiences may play a part in influencing the development of facial emotion recognition, such as exposure to emotional displays (Gordon, 1989) and levels of expressivity of significant others at home (e.g., Camras et al., 1990).

Secondly, neurological development may influence facial emotion recognition.

This research focuses on how developments in the brain during childhood years between 5 to 11years may influence a child’s emotion recognition ability. Researchers who have explored the brain’s role in the development of emotion recognition have tended to focus on developments of specific brain regions, as well as strength of lateralisation (right and left hemisphere) for emotion processing; this research focuses on the latter. Researchers have extensively investigated how emotion processing is lateralised in the adult brain; however, the development of emotion lateralisation over childhood is under examined and little if anything has explained individual differences seen in children’s facial emotion recognition skills.

Understanding the developmental trajectory of facial emotion recognition and more specifically the neural markers of this development in healthy child populations is crucial. Further exploring how lateralisation for emotion processing may influence children’s emotion recognition skills throughout childhood will allow one to develop an enhanced understanding of the normative development of emotional recognition; not only can we inform knowledge of deviance or psychopathology and integrate this better understanding into the design and provision of prevention and intervention, but we can also enhance our understanding of the risk factors that might influence normative development and lead to an emerging disorder (Cicchetti and Rogosch, 2002).

This chapter is a review of the current understanding of development of emotion recognition skills and lateralisation of emotion processing, and will discuss how the research reported in this thesis will advance this understanding.

1.2 Development of emotion recognition abilities from faces

Research in the development of children's ability to recognise emotion from faces has consistently shown that emotion recognition skills from facial expressions are an ability that develops gradually, between 4 and 11 years old (Gao & Maurer, 2009). Furthermore, this ability does not appear as a complete, developed package; rather, different emotions are recognised at different stages of development with happiness reaching plateau earliest, followed by sadness or anger, then surprise or fear, and finally emerging the emotion of disgust (Widen & Russell, 2003; Herba & Phillips, 2004). As mentioned before developmental affective research so far has used a variety of tasks with each task examining different underlying processes; for instance emotion labelling, identification, and discrimination examine the child's emotion knowledge, whereas emotion matching examines the child's ability to visually discriminate between emotions. As a result of using differing tasks researchers report slightly different ages at which different emotions are recognised; however, the general order remains quite consistent in which emotions can be identified, recognised, and matched. Boyatzis et al. (1993), for instance, examined facial emotion recognition ability in 3, 4 and 5 year old pre-schoolers. They reported the expressions of happiness, sadness and surprise to be recognised accurately more easily than those of fear disgust and anger. Anger was the most difficult to recognise. Significant development was found for the emotions of fear and anger between 3 ½ and 5 years of age. Reichenbach and Masters (1983) examined the development of emotion recognition from faces and contextual cues in children. They asked 4 and 9 year olds to judge the emotion expressed by facial photographs and the emotion elicited by certain stories (vignettes). They demonstrated that children as young as 4 years were able to correctly judge happy emotion with accuracy over 85%, while they were less accurate in judging sadness (62% accuracy, misjudged sad faces as neutral), anger (56%) or neutral expressions (43%), but 9 year olds were significantly more accurate than 4 year olds in the recognition of sadness. Furthermore, Vicari et al. (2000) examined the development of emotional facial recognition skills across two kinds of tasks; more specifically they investigated whether visual emotion discrimination (matching facial expressions) develops in a similar fashion to emotional labelling skill which recruits knowledge of emotional terms, using an emotion matching and an emotion recognition task using three groups of children, 5-6 year olds, 7-8 year olds, and 9-10 year olds. The results for the recognition tasks indicated high accuracy in 5 year olds for happiness and sadness. Significant improvement between the ages of 5 and 10 years was found for disgust, surprise and to a lesser degree for fear.

In matching task happiness, disgust and surprise were matched with high accuracy in 5-year-olds. Significant improvement between the ages of 5 and 10 years was found only for anger and fear. These two patterns of development were suggested to indicate very different cognitive abilities that different tasks recruit. Nevertheless, the study showed similar developmental trajectory of emotion recognition ability for different emotions to other studies.

Whereas the above studies obtained evidence of the varying developmental pattern across emotions, Durand et al. (2007) compared the facial emotion recognition skills of children to adults, allowing the researchers to determine at what age children reach adult levels of recognition. They showed 5 to 11 year olds and adults photographs of faces depicting one of the six basic emotions (happiness, sadness, anger, fear, disgust and neutrality) to explore at what age children’s emotion recognition skills are comparable to those of adults. The ability of the children to discriminate a target emotion from other emotions improved with age and children as young as 5 and 6 years appeared to accurately recognise happiness and sadness with accuracy levels close to that of adults. Children’s recognition of fear reached an adult accuracy level around the age of 7 years. Additionally at this same age, 7 years, children’s accuracy of anger matures and reached the level of adults, while the recognition of neutral faces reached adult level at the age of 8 years. It was only around 11 to 12 years that children’s ability to process disgust improved enough to reach the adult level.

Evidence from Kolb and colleagues (1992) demonstrated that children are able to recognise an emotion in one face and then identify a second face who is expressing the same emotion or the context in which the emotion would be experienced. In their study they aimed to look at the developmental changes in the ability of children to recognise facial expressions and also explore the relationship between these changes with changes occurring during cortical development. They gave three groups of children from 6 through to 11 years of age and adults a facial expression matching task and a cartoon face matching test (a cartoon is shown which depicts different situations where one character is drawn with a blank face and one has to choose a face with the appropriate emotion for the character of the cartoon) They used facial expressions of happiness, sadness, fear, anger, disgust, and surprise. Overall, facial emotion recognition improved between 6 and 8 years and between 9 and 10 years of age, and then between the ages of 13 and 14 years of age. This study also provided evidence of the different developmental trajectories of different emotions: Recognition of happiness at 6 years was as good as that by adults, whereas recognition of sadness, surprise, and disgust did not reach adult accuracy level until the age of 14. Interestingly, in addition to the finding that emotion recognition skills improve with age, Kolb et al. found that the performance of the children from 8 to 13 years old was comparable to that of adults who had frontal lobe injuries. This finding is important as it links the emotion recognition skills with maturation of brain structures involved in the development of these skills and is going to be looked at in following sections.

It was highlighted earlier that researchers have found differing developmental trends for emotion recognition and part of this may be because of the task. In addition to exploring accuracy for emotion recognition and matching, researchers have also explored emotion recognition using less explicit measures. For instance, it is possible to use a more sensitive measure to identify developmental changes, such as the speed of processing (Chung & Thomson, 1995). De Sonneville et al. (2002) and Herba et al. (2006) both explored children's accuracy and speed of processing. Both studies reported that with increasing age children become faster in facial emotion recognition. It was suggested that this increase was due to increased efficiency in the ability to encode faces. What is particularly interesting are the trends found for emotion recognition accuracy and speed. For instance, De Sonneville et al. (2002) had 7 to 10 year olds and adults complete three facial emotion processing tasks: emotion identification, facial expression matching, and recognition of dynamic emotions (video of morphed facial expressions) with four basic emotions (happiness, anger, fear, and sadness). Measures of accuracy and response times were taken on all these tasks. They showed that while speed of processing increased with age there was greater variability in the age when children became proficient at recognising emotions (accuracy): particularly accuracy was highest for recognition of happiness, anger and fear, and lowest for sadness. Significant improvement in accuracy for sad expressions was found between 7 and 10-years-old. More specifically the sadness mean error rate decreased from 17% at the age of 7 to 8% at the age of 10 years which was taken to indicate that the prototype representation of a sad expression improves with age.

1.2.1 Refinement of emotion recognition skills: Recognising emotions at different levels of intensity

Whilst children with age become increasingly experts in recognising prototypical exemplars of the basic emotions in their 100% intensity, children mostly in their everyday life see lower intensity facial expressions more frequently than full intensity facial expressions. Therefore, when considering the development of emotion recognition it is important to explore children's sensitivity to nuances in emotions conveyed in facial expressions of lower intensity and understand the subtleties of emotional processing. Describing and understanding the normative development of subtle emotional processing could shed some light on emotional difficulties which might appear especially in late childhood (Thomas et al., 2007). Additionally, researchers have often explored emotion recognition sensitivity with participants who were vulnerable to psychiatric disorders which may manifest between 9 and 16 years of age (Costello et al., 2003). For example, Blair et al. (2001) investigated the sensitivity of children with psychopathic tendencies to identify emotions at different intensities for fearful and sad expressions. They found that children with psychopathic tendencies needed significantly more intensity to recognize the sad expression. While this is not one of the key focuses for this research it does indicate that there are individual differences in children's recognition of emotions at differing intensities.

There are few studies which investigate sensitivity of children to subtleties of emotion displays in different intensities of facial expressions. Herba et al. (2006) explored whether different intensities of emotions would affect the facial emotion processing skills of children from 4 to 15 year olds using an emotion matching task. They found that children’s accuracy significantly improved with increasing intensity, for most emotion categories but particularly for fear and happy expressions, with higher levels of emotion intensity (i.e., 50%, 75% or 100%) compared with 25% intensity. Furthermore, children were generally faster to match higher intensity expressions than the lower (25%) intensity expressions, particularly for sad, disgust, and happy expressions.

Montirosso et al. (2010) examined the effect of the intensity of emotion expression on children’s developing ability to label emotion of five facial expressions (anger, disgust, fear, happiness, and sadness) at four levels of intensity (35%, 50%, 75%, and 100%) with five groups of children from 4 through to 18 years of age (4 to 6 year olds, 7 to 9 year olds, 10-12 year olds, 13-15 year olds, and 16-18 year olds).They found greater accuracy with greater intensity and that this difference varied with age and with emotion. Specifically, 4 to 6 years old children were significantly less accurate to recognise the emotions at 35% level of intensity compared with all the other age ranges. At 50% and 75% levels of emotion intensity they did not differ from 7 to 9 year olds. However, the 7 to 12 year olds were less accurate than adolescents when identifying the presence of an emotion in a face at 35% and 50% intensity. Additionally, they found that anger and sadness were the most difficult to recognize at 35% intensity. Across the four levels of intensity, sadness was recognized as accurately as disgust at 50%, while anger was only recognized as accurately as disgust and sadness at 75% intensity, and fear was recognized as accurately as disgust at 100% intensity. It is interesting that those emotions recognised more accurately at lower intensities are those that are identified as being recognised earlier in age when looking at emotion recognition more widely (e.g., Reichenbach & Masters, 1983; Gao & Maurer, 2009).

Along similar lines Thomas et al. (2007) examined sensitivity differences to changes in emotional intensity of fearful and angry facial expressions between children 7 to 13 years old, adolescents (14 to 18 year olds), and adults on a binary forced-choice discrimination task using fearful and angry expressions of different intensities. Sensitivity to fear increased linearly across the three age groups, whereby the older age groups were more sensitive to the presence of the emotion at lower intensities than the younger age groups. This was not the case for anger which only increased markedly from adolescence to adulthood only. This work demonstrates that sensitivity to identifying fear and anger as being present at lower intensities may not occur until adulthood. Additionally, participants can identify the presence of fear at lower intensities earlier than the presence of anger at similar intensities. The importance of this behavioural finding lies in the fact that it is consistent with neurological findings that the prefrontal cortex (PFC, specific to anger processing, Adolphs, 2002; Davidson, 2004; Diamond et al., 2002) develops later than the amygdalae (specific to fear processing) and the late development of sensitivity to anger may relate to the neural maturation of the PFC that continues through adolescence (Diamond et al., 2002; Kolb et al., 1992).

Many of the aforementioned studies used intensities that were quite different (e.g., 25%, 50%, 75%, and 100%). Gao et al. (2009) expanded on this work to explore children's (5, 7, and 10 year olds) and adults' sensitivity to emotion expressions with ten intensity levels for the 5 year olds and twenty intensity levels for the 7 and 10 years old and adults. Additionally, they investigated whether the developmental trajectories for happiness, sadness and fear at lower intensities are comparable to those reported for 100% intensity, and explored errors in emotion detection. Gao and colleagues found that from the age of 5-years children were as sensitive as adults to detect happiness and sadness in a face but their accuracy in discriminating different intensities of happy and sad expressions improved from 5 to 10 years of age. All children, 5, 7 and 10 year olds, were significantly more likely to falsely judge the facial expression of sad as fearful. For fear the 5-year-olds were significantly less accurate than the adults at the intensities higher than 60%, but the 7-year-olds and 10-year-olds' sensitivity and misidentification rates did not differ significantly from that of adults.

The above studies considered emotion recognition at varying levels of emotion intensity. It is clear that with age children require less emotion to be present in a face for the emotion to be recognised, thus demonstrating a clear development in emotion recognition skills.

1.2.2. Development of emotion conceptual system

In the previous subsection it was demonstrated that there are developmental trends for the recognition of the 6 basic emotions, where the children's ability to recognise some emotions emerges later than others. Importantly, these findings are not confirmation that young children do not experience or understand facial expressions of emotion. On the contrary, research has shown that infants as young as 7 months old are able to discriminate between the emotions of happiness anger and fear (Kestenbaum and Nelson, 1990). In fact, there is evidence that the facial expressions of others may alter infants' behavioural responses such as expression of interest/surprise and looking time (Montague & Walker-Andrews, 2001), thereby possibly demonstrating that they infer psychological intent behind emotional expression

It is widely accepted that there are basic emotion discrimination skills that develop and are refined gradually with age. The review above described the development of facial emotion recognition ability during middle childhood which is refined to recognition not only of wider range emotions bur also their different levels of intensity. One question arising is whether the way emotions are perceived across the childhood is qualitatively similar to that of adults, or in other words, what develops? This question was tackled by Bullock and Russell, (1985) and Widen and Russell (2002, 2003, 2008).

Bullock and Russell (1984, 1985) put forth the idea that children's interpretation of facial expression is an act of categorization. They proposed three properties of the emotion categories. First, the categories are fuzzy, which means their boundaries are not distinct. It is possible that one category may apply to more than one emotional expression and one emotional expression may belong to more than one category. Second, the categories of emotions are organised in a circular mode, with respect to one another. In Bullock and Russell's structural model the nine emotion categories (happy, excited, surprised, afraid, angry, disgusted, sad, sleepy and calm) are ordered in a way that more similar emotions are closer together. Distance between emotions in the structure represents dissimilarity, and proximity represents similarity. Therefore, sad is opposite to happy whereas anger and fear are similar because they are adjacent in the model. Most likely, an emotion is miscategorised because it is placed in an adjacent category. Third, the categories are interrelated along two dimensions, with the horizontal dimension representing the level of pleasure or displeasure (e.g., happy is associated with pleasure and disgust is associated with displeasure) of the emotion and the vertical dimension representing the level of arousal (e.g., surprised is associated with high arousal and sad or calm is associated with low arousal).

To explore their ideas, Bullock and Russell (1985) examined 2 to 5 year olds' and adults' categories of emotions. They showed participants a pair of faces and asked them to select the one that feels '*X*' (e.g., select the face that feels happy, when happy was the target emotion). Bullock and Russell also examined the pleasure and arousal dimensions by showing participants three facial expressions varying along the pleasantness dimension (keeping the arousal dimension constant) and three facial expressions varying along the arousal dimension (keeping the pleasure dimension constant). The participants were asked to match two of the three faces that expressed similar emotions. Bullock and Russell demonstrated that even children as young as 2 years old were able to recognise the target expression for each of the six basic emotions (happy, sad, angry, fear, disgust and surprise) significantly above chance; however, when compared with adults performance they found that the children's categories of emotions were broader than those of adults in the sense that children selected certain expressions as exemplars of a wider category of pleasure and arousal. The findings from this study provide evidence that children understand emotions from facial expressions but in a different way to adults. During the course of development the child's conceptual system of emotion changes; specifically, younger children initially have emotion categories which are broad, encompassing all similar emotions in terms of pleasure and arousal, but with age these emotion categories narrow systematically until it resembles the adult conceptual system. In other words, as children develop they appear to differentiate and divide the broad categories of pleasant and unpleasant emotions or high arousal and low arousal emotions into finely defined distinct emotions, thereby becoming more accurate in emotion recognition.

Widen and Russell (2002, 2003, and 2008) extended Bullock's and Russell's work by using free labelling task of the six basic emotions described by

Ekman and Friesen (1978). More specifically, they examined what labels children applied to faces at different ages and whether the emergence of specific labels was systematic. Across their studies, children 2 to 5 years old participated. They assessed children's knowledge of emotion labels and how accessible these labels were. The two groups of 3, and 4 year olds, completed an emotion priming task and then all children performed an emotion labelling task. The priming task aimed to encourage children to produce as many emotion labels as they could. If a child did not produce a label, the experimenter would help and prime the production of this label by telling a story and discussing with the children the appropriate emotion label which he/she had difficulty to produce. In the free emotion labelling task, children were shown a picture and asked to label different facial expressions of emotion. The findings of the priming task indicated that the ease of eliciting each different emotion term varied with emotion. Children were significantly better able to elicit the labels of sad, happy and angry than the labels of scared, disgusted and surprised. These findings demonstrate that labels, even if they are acquired, vary in accessibility. The findings of the free emotion labelling task indicated that the number of different emotion labels children used increased with age and that the labels emerge systematically with age. When a child used only one label this was typically happy; for instance, the 2 year olds used the label of happy for most other facial expressions of emotion (exception was when an angry face was presented). With age children became more narrow as to what facial expression of emotion would fit with which label. Three year olds would use the label of happy for surprised and fearful faces as well as the happy faces (which they more frequently labelled as happy than the 2 year olds), and the 4 and 5 year olds used the label of happy less frequently for surprised and fearful faces and more frequently labelled happy faces as happy. Similar patterns were used for the sad and angry categories. As the number of labels increased (for each additional number of labels used) children would keep the previous label(s) and additionally use one more. For instance, if used two labels a child would add the use of angry, if used three labels a child would add the use of sad, if used four labels a child would add the use of surprised, if used five labels a child would add the use of scared, and if used six labels a child would add the use of disgusted. This pattern applied to 67.5% of the children. However, as 32.5% did not fit this simple pattern, Widen and Russell suggested a more complex pattern whereby happy emerges first. If two labels emerged some children added angry, others added sad. For three labels all children used happy, angry and sad. At the next step some children would add surprised and some scared, and for five labels, again there was one path, all children used happy, angry, sad, surprised and scared. At the last step, disgust was added. Interestingly, these findings show that while initial labels are quite broad (i.e., when have fewer label categories), the added labels are narrow. Unlike happy, sad, and angry, the later arising labels of surprised, scared and disgusted are applied more narrowly from the start. Even when the labels are in the child’s vocabulary (shown in the priming task) they are not easily accessible. Indeed, findings showed that 100% of children used the label disgusted and 93% labelled the disgusted face, yet, only 13% labelled the disgusted face as disgusted. This shows that a label of emotion might appear in children’s lexicon before they are able apply it as the concept of the label may be still developing. The above findings show children's fine-tuning of facial emotion recognition ability through the development of their conceptual knowledge of emotions and this is consistent with earlier work discussed that explored the refinement in the increasing recognition of subtle (lower intensity) emotion expressions.

Importantly, the development of emotion recognition abilities at different times across childhood for different emotions might not mean that young children do not experience or recognise the emotions. In this section we see from the emotion conceptual system as proposed by Bullock and Russell (1985) and Widen and Russell (2003) that emotion categories exist in young children as broad categories, but they are poorly defined with fuzzy boundaries. In order to unravel and better understand this evidenced development for emotion recognition in faces, it is important to consider the mechanisms that drive such development; what is it that develops when a child's performance in facial emotion recognition improves?

1.3 Mechanisms of facial emotion understanding development

With face recognition development McKone, Crookes, Jeffery and Dilks (2012) suggested that all key mechanisms for face recognition (encoding, holistic processing and face responses in neuroimaging) mature early in a child's life. This conclusion is consistent with survival needs of children to reliably identify a face early in their lives.

With the development of emotion recognition there are two aspects which researchers have tried to understand and reveal the mechanisms underlying such development. The first emphasises the role of cognitive factors (processing of facial features in emotion recognition) and the second emphasises maturational factors and gives neuropsychological explanations for the developmental pattern of facial emotion recognition (e.g., the development of brain lateralisation in the perception of affective stimuli and maturation of structures relevant to emotion processing). These two accounts complement one another as cognitive processing may be dictated by the maturation and development of relevant structures (Chung and Thomson, 1995).

1.3.1 Facial features in emotion recognition

Differences in the salience of processing facial features and a shift from featural/analytical processing to a holistic/configural processing of facial expressions have been suggested as driving children's development of facial emotion recognition skill (Cunningham, & Odom, 1986). Perhaps age differences in facial emotion recognition are explained from the developmental change in the facial features children rely on when they judge a facial expression or the way they see the face (holistically or analytically). Indeed, the development of children's ability to recognize facial emotion has been investigated in relation to the role of the ability of children to process "configural information". The term was introduced by Carey and Diamond (1977) to indicate the interrelationship between different facial features (e.g., the shape and positioning of the mouth in relation to that of a nose, eyes etc.). Diamond and Carey (1986) identified two forms of configural information that they referred to as first-order and second-order relational properties. The former refers to the relative position of the facial features that make a face: two eyes positioned horizontally, above the nose, above the mouth. The second-order relational properties refer to the spatial interrelationships between different features more generally referred to as configural features (e.g., the distance between the eyes, position and shape of the nose in relation to the position and shape of the mouth). What led to this line of investigation are the findings that configural information plays an important role in facial emotion recognition by adults (shown by Calder, Young, Keane, & Dean, 2000, and Calder & Jansen, 2005). Processing of configural features is seen as holistic processing and it is distinct from the analytical or featural processing of the individual features of the face (Calder, et al. 2000, Durand, Gallay, Seigneuric, Robichon, & Baudouin, 2007).

Durand et al. (2007) explored this idea, that the development of the ability of children to process configural information of faces underlies the development of the ability to recognise emotions from faces with four groups of children of ages ranging from 5-12 years and one group of adults. They found that children as young as 5 years process facial emotion in a configural/holistic way. Configural processing did not seem to play a crucial role in the development of facial emotion processing. These findings, however, contradict other studies which found that featural processing at young age develops into configural processing of facial emotion information. Kestenbaum (1992) for instance, investigated the differences in emotional expression recognition across childhood in terms of a gradual shift from configural/holistic processing of the face towards analytic processing in the recognition of emotional expressions. Children at 5 and 7 years and adults were presented with pictures of four emotional expressions (happiness, surprise, fear and anger) with different parts of the faces presented alone without any other facial information. To explore featural or analytical processing the expressions were presented showing only the mouth, only the eyes, or the combination of the mouth and eyes. To look at the configural or holistic processing, participants were shown both the full expression and the full expression without the nose (always saw both eyes and mouth). The masking of the nose could not disrupt featural analysis but could disrupt the configural processing. There were two conditions: in the discrete emotion condition, participants had to press a button for each of the target emotions. The global categories condition was the same except for the general target terms: namely, feels good / feels bad. Individual features were found to be better for identifying global categories (feels good versus feels bad) than discrete emotions. For the discrete emotions, though, developmental changes of the type of processing of emotional expressions varied with the ease of recognition of particular emotions. For instance happiness, which is universally the easiest emotion to recognize (Reichenbach, & Masters, 1983), is processed basically on its most salient feature, the mouth. This is the same for all ages. Developmental changes were more apparent for anger and fear, which are more difficult emotions to recognize. Younger children's (5 years old) processing of fear was based on single features (eyes), whilst older children (7 years old) and adults used multiple features (add mouth to the eyes) and a more configural processing. The finding perhaps indicate that there is a continuum of processing from reliance on individual features (analytical or featural processing) to a more holistic processing of combination of features and that recognition of each emotion follows different courses of development along this continuum.

A similar developmental trend was suggested by De Sonneville, Wrschoor, Njiokiktjien, Veld, Toorenaar, and Vranken (2002) who looked at the development of processing strategies (holistic/configural versus analytic/featural) across ages using recognition of emotions and matching emotions tasks which underlie a different type of required processing strategy. Whilst identification is thought to be facilitated by making use of configural information, matching of emotions requires the matching of particular facial features and thus activates a less efficient piecemeal encoding process. They looked at the speed of processing facial emotion information as a marker of development. They postulated that a measure of speed may indicate qualitative differences between the two strategies (holistic/analytic) in processing facial information. The configural processing is automatic and fast, whereas analytical or featural strategy is slower as it processes information in terms of their components and it proceeds in analytical and attention demanding way. De Sonneville, et al. (2002) found that the speed of processing improved for all the basic emotions and this was taken to suggest a shift from an analytical-featural processing to a holistic, configural and more automatized processing. Adults, after controlling for general increases in reaction time, were found to be twice as fast as children demonstrating more developed and efficient configural processing.

In summary, research into the processing of facial features has provided some evidence of its relationship with facial emotion recognition across childhood. There is a developmental change in the way children process facial information from featural to configural way of processing. These changes in processing style reflect cognitive developments, which in turn could be explained through exploring developmental changes of the maturation of underlying brain structures, such as developments of the corpus callosum. More generally, it could be the hemispheric development where one hemisphere may become specialised for facial emotion processing. In fact this account of emotional processing development, the maturational account, may be a better predictor of children's increasing facial emotion recognition skills. The brain's hemispheric specialisation for processing different information has been shown for a variety of skills; for instance, language is specialised to the left hemisphere (Pujol, Deus, Losilla, & Capdevila, 1999), face recognition is specialised to the right hemisphere (Demaree, Everhart, Youngstrom, & Harrison, 2005). The next sections will explore hemispheric asymmetry for emotion processing in adults, the valence hypothesis, and the right hemisphere hypothesis. If the strength of hemispheric lateralisation for emotion processing develops throughout childhood (i.e., becomes more strongly specialised to one hemisphere) it could explain emotion recognition performance across the lifespan.

1.4 Hemispheric lateralisation for emotion processing: Evidence from adults

Researchers have debated the contributions of the two hemispheres to the processing of emotions for many years. Goldstein (1939) was first to notice that damage to the left side of the brain resulted in a "catastrophic" emotional reaction whereas damage to the right side of the brain resulted in emotional indifference and tendency to joke (Gainotti, 1972). Perria, Rosadini and Rossi (1961) in a study of sodium amylobarbitone injection to the left or right carotid artery reported comparable findings. Diamond, Farrington and Johnson (1976) showed neurologically intact participants cine films to their left or right visual fields and found evidence that the two hemispheres contribute in different ways in emotion processing.

In contrast to the work that has not found any evidence of hemispheric specialisation, numerous studies employing behavioural measures, neuropsychological measures, and neuro-imaging methodologies (PET, fMRI, ERPs) with both brain-damaged (patients with lesions in either hemisphere) and neurologically intact participants have tried to gain insight into the way the brain mediates emotion processing (Adolphs, 2002; Roadway, Wright, & Hardie, 2003; Compton, Wilson, & Wolf, 2004). These findings have led to the idea that the right hemisphere has a leading role in emotion processing.

Nevertheless, there have been studies which have reported no hemispheric differences in the processing of any of the facial expressions as they failed to find a visual field by valence interaction or visual field advantage for the processing of facial expressions (e.g., Hirschmann & Safer, 1982; Prigatano & Pribram, 1982; Thompson, 1983). A meta-analysis of 106 PET and fMRI studies of human emotion processing was completed by Murphy, et al. (2003), which also did not support the idea that any of the hemispheres has a primary role in emotion processing. On the contrary, the meta-analysis demonstrated equivalent activation of the two hemispheres when processing emotion. However, there is robust evidence of the special role which the right hemisphere plays in emotion processing and this is going to be discussed in the next section.

Thus, within the above debate two major theories of hemispheric lateralisation of emotion processing arose: the Valence Hypothesis (VH) and the Right Hemisphere Hypothesis (RHH). Both have received considerable support by studies with adults that employed different methodologies (Asthana & Mandal, 2001; Borod et al., 1998; Bourne, 2005, 2008, 2010; de Gelder, & Geminiani, 2006; Fukui, & Yonekura, 2001; Jansari, Tranel, & Adolphs, 2000; Jansari, Rodway, & Goncalves, 2011; Kestenbaum, & Nelson 1992; Ley and Bryden, 1979; Narumoto, Okada, Sadato, Tamietto & Corazzini, 2001) and are outlined below.

1.4.1 Right Hemisphere Hypothesis

The Right Hemisphere Hypothesis (RHH) posits that the right hemisphere plays a dominant role in processing all emotions and emotional behaviour, including the perception, expression and experience, regardless of valence (both positive and negative; Borod, 1998; Demaree et al., 2005; Killgore et al., 2007; Murphy et al., 2003). The evidence supporting the Right Hemisphere Hypothesis for adults is consistent across studies using varied methodologies with unilaterally brain damaged patients and neurologically intact participants.

Initially, the association between right hemisphere and emotion processing was suggested by observations of patients with unilateral right side lesions and their impaired emotional processing, (Gainotti, 1969, 1972; Borod et al., 1998; Demaree et al, 2005; Perria et al., 1961).

More recently, also, there is fairly robust evidence pertaining to hemispheric specialization for emotion processing from studies with unilateral brain damaged adults that support the right-hemisphere hypothesis. Mostly, these studies focused on two channels of emotional understanding and communication: facial expressions and emotional prosody (emotional intonation and emotional speech).

For example Kucharska-Pietura and David (2003) compared the performance of 30 RH brain-damaged patients (RHD) patients, 30 LH brain-damaged patients (LHD) patients, and 50 healthy controls on both facial expression and emotional prosody recognition tasks. They found that right hemisphere patients were markedly impaired relative to left hemisphere and healthy controls on their performance. In a second study Kucharska-Pietura and David (2003) found that RHD showed a significantly reduced left visual field bias (right hemisphere) compared to controls when they saw sad and happy emotions in a chimeric faces test.

The chimeric faces test capitalizes on the crossed nature of the visual system which projects information from one half of the visual field directly to the opposing hemisphere. Emotional chimeras are faces made to show an emotional expression on one half of the face and a neutral expression, from the same poser, on the other half. A chimera is presented centrally with its mirror image, one above the other (see section 2.2.2). The question asked in a chimeric faces test is which of the two faces is more emotional. The LHDs and non-clinical controls showed similar left visual field bias (LVF, right hemisphere) for the task.

Left visual field bias for facial emotion processing has been reported by other studies which have used the chimeric faces test with emotional chimeras. Initially Levine and Levy (1986) investigated hemispheric asymmetries for processing chimeric faces and reported a left visual field bias (LVF, right hemisphere) bias for processing happy chimeras. Luh, Rueckert, and Levy (1991) also found strong left visual field bias for emotion processing using happy chimeras. Furthermore, Christman and Hackworth (1993) found the strong LVF bias using chimeras with positive (happiness, pleasant surprise) and negative valence emotions (sadness, anger). More recently, Ashwin, Wheelwright, and Baron-Cohen (2005), reported a LVF bias for both happy and angry chimeric faces; Coolican, Eskes, McMullen, and Lecky (2008) reported similarly for happy chimeras. Workman, Peters, and Taylor (2000) demonstrated an overall left visual field advantage when participants saw chimeras with the basic emotions of happy, sad, angry, fear, surprise, pleasant and surprise (grouped as pro-social, anti-social emotions) and finally Bourne in a series of studies (2011a, 2011b, 2010, 2008a, 2008b, 2005) found a left visual field bias for processing 6 basic emotions (happy, sad, angry, fear, surprise, disgust).

The above findings are consistent with other earlier studies with brain-damaged patients, which also reported that the RH brain-damaged patients were more impaired than LH brain-damaged patients in the recognition of emotions in facial expressions. The impairment found was distinguished from deficits in processing facial identity indicating that the RH is particularly implicated in emotion recognition (Bowers, Bauer, Coslett, & Heilman, 1985; DeKosky, Heilman, Bowers, & Valenstein, 1980).

Evidence for a specialisation of right hemisphere structures for perception of emotion has been reported in functional neuroimaging (fMRI) studies with non-clinical participants. For instance Narumoto et al. (2001) tested the effect of the explicit attention to the emotional expression of the faces on the neuronal activity of face specific regions. They found that selective attention to facial emotion specifically enhanced the activity of a structure in the right hemisphere the superior temporal sulcus (STS), compared to attention to faces per se. Further, Sato, Kochiyama, Yoshikawa, Naito and Matsumura, (2004) measured brain activity by fMRI when subjects were passively observing facial expressions. Sato reported higher activation during viewing of emotional facial expressions relative to neutral facial expressions over the occipital and temporal cortices of the right hemisphere.

The RHH has been supported in studies using Divided Visual Field (DVF) methodology, where the stimulus is presented in the left visual field (right hemisphere) or the right visual field (left hemisphere). Ley and Bryden (1979), Lavadas, Umilta, and Ricci-Bitti (1980); Strauss and Moscovitch, (1981); all reported a left visual field superiority of emotion recognition in emotion processing regardless of the type of expression. Additionally, findings from EEG studies led support for the special role of the RH in the recognition of emotions from faces. Despite the fact that EEG research has its emphasis on the timing of the emotional processing, nevertheless investigators have reported lateralisation of brain activity in emotional processing. Kestenbaum, & Nelson, (1992), Laurian, Bader, M., Lanares, J., & Oros, (1991) Munte, Brack, Grootheer, Wieringa, Matzke, & Johannes, (1998) and Kayser, Tenke, Nordby, Hammerborg, Hugdahl, & Erdmann, (1997) are some of the earliest EEG studies to find evidence for a differential hemispheric contribution in the perception of emotion with the main characteristic a greater overall involvement of the right hemisphere. Further evidence from electrophysiological studies are discussed in section

1.4.2 Valence Hypothesis (VH)

Valence is a fundamental dimension of emotion and refers to the direction of behavioural activation associated with emotion, either pleasant emotion or unpleasant stimulus (Lane, Chua, & Dolan, 1999).

The Valence Hypothesis contends that emotional processing has different asymmetry patterns across the two hemispheres. More specifically, the VH proposes that the pattern of hemispheric asymmetry depends on the valence of the emotion so that right hemisphere (RH) is rather specialized for processing negative/unpleasant emotions (sadness, fear, anger and disgust) whilst positive/pleasant emotions (happiness and surprise) are processed by the left hemisphere (LH; Davidson 1992).

A number of studies using different methodologies lend support to the valence hypothesis. Jansari et al. (2000), Jansari et al. (2011), Reuter-Lorentz et al. (1981, 1983) all found a valence-specific laterality effect using a free viewing laterality task of emotion discrimination, where a pair of faces, side by side, is presented centrally (one face of the pair, therefore, was placed at the left side of the centre and the other was placed at the right side of the centre). The participants were instructed to select the face which best depicted the emotion corresponding to a given emotion label. The positive emotion of happiness was more accurately identified when presented to the right of centre; indicating LH processing. In contrast, the opposite was true for negative emotions; emotions were more accurately identified when presented to the left of centre, indicating RH processing. Reuter- Lorentz and Davidson (1981) found this effect in reaction times as well as accuracy. Rodway et al. (2003) using the same free viewing laterality task reported the same pattern of processing but only for female participants. Asthana and Mandal (2001) used a divided visual field (DVF) paradigm. In the DVF task images are presented either to the left or right of the centre of the screen due to neuroanatomical structure of the visual system (see section 2.2.2), one at a time and RTs were taken. Asthan and Mandal (2001) found a left visual field superiority (LVF) indicating RH processing only for sad faces. They found no hemispheric advantage for happy emotions.

In addition to exploring hemispheric lateralisation using behavioural measures (such as the DVF and the free viewing laterality task), EEG work has also been completed and supports the Valence hypothesis. Krolak-Salmon, Fischer, Vighetto, & Mauguiere (2001) aimed to explore neurophysiologic activation when presented with positive and negative facial expressions of emotion. They reported differential activity in processing of positive (happiness) and negative (fear) emotions. The activity related to happiness was spread more widely over the left hemisphere, than was the activation to fear (Adolphs, Damasio, Tranel, & Damasio, 1996). The processing of fear was predominantly observed in the RH, which is consistent with the presumed role of the RH in urgent and threatening situations (Adolphs, et al., 1996; Van Srien & Morpugo, 1992).

The above review clearly shows that the negative emotions are more likely to be processed in the right hemisphere. However, it is less clear how positive emotions are processed.

1.4.3 Approach-withdrawal model of emotion processing

In addition to the valence hypothesis, there is a similar model: the approach-withdrawal model of emotion processing. The two models overlap extensively as most negative emotions (fear, disgust) elicit withdrawal behaviour and most positive (happiness, surprise) elicit approach behaviour. According to the approach-withdrawal model/hypothesis, which is mostly pertinent to emotional experience and behaviour, happiness, surprise, and anger are classified as approach emotions, since they drive the individual towards the environmental stimuli. Sadness, fear and disgust result in withdrawal behaviour as they drive the individual away from aversive stimulation in the environment. Of note, empirical evidence for approach-withdrawal model showed that emotional experience is also lateralised within frontal brain regions, namely approach behaviour/positive affect in left prefrontal cortex and withdrawal behaviour/negative affect in the right prefrontal cortex (Demaree, Everhart, Youngstrom, & Harrison, 2005; Sutton & Davidson, 1997). While there are these two models (valence hypothesis and approach-withdrawal) most evidence focuses on assessing the valence hypothesis.

Adolphs (2001) followed up Jansari, et al. (2000) study investigating patients with LH or RH unilateral brain damage. Their data supported the valence hypothesis with regard to the recognition of emotions from facial expression and that there is a LH bias for processing positive emotions and a RH bias for processing negative emotions. However, they also reported contributions by the two hemispheres in the processing of positive valence emotions as they found a significant superiority for both the individuals with LH brain damage and RH brain damage in comparison to normal controls in discriminating happy faces when shown on the LVF; this finding does not fit with any of the models of explanation cited above, (i.e., the Right Hemisphere Hypothesis and the Valence Hypothesis). Adolphs speculated that there might be a bilateral equal hemispheric contribution to processing of positive valence emotions but the particular hemispheric contributions to such processing remains elusive.

1.4.4 Reconciling the Valence and Right Hemisphere Hypotheses

It is quite clear that whilst the RH hypothesis has received the most consistent support it has been difficult to reconcile it with a number of other reports which suggest a valence specific hemispheric organization of emotional processing.

In the light of the inconsistencies of the above evidence, Tamietto, et al. (2005) presented happy and fearful faces to the LVF, RVF and bilaterally. This differs from many other studies that have primarily presented emotive faces to either the LVF or the RVF and allows for an analysis of inter-hemispheric transfer. Findings indicated clear support for a model that recognition of emotions is lateralised in the RH. However, a gain was observed in the bilateral visual field presentation condition, indicating that the LH is not inert but it contributes to emotional processing. The latter clarifies the nature of the hemispheric specialization as relative rather than absolute.

Likewise, Compton et al. (2005) tested the hypothesis that communication between the two hemispheres would be facilitated for emotional compared to neutral faces. They found a bilateral advantage which was greater for angry and happy faces compared to neutral faces as measured with both accuracy and reaction time measures. Along similar lines, Killgore and Yurgelun-Todd (2007) set out to examine whether the underlying neural processes of the two competing theories of lateralised emotion processing show that the Right Hemisphere Hypothesis and the Valence Hypothesis can be reconciled. In an fMRI study, chimeras masked by a full neutral face were presented unilaterally. When all emotional faces were presented unilaterally to the LFV the researchers found a consistently greater activation within the posterior RH compared to identical lateralised presentations of affect to the RVF, findings which are consistent with the RH hypothesis. However, their study provided support for the valence hypothesis as well. The magnitude and extent of activation produced by the LVF stimuli, was modulated by the valence of the stimuli. Specifically, there was observed a greater responsiveness to the LVF presentations of sad relative to happy faces which suggests that the RH is specialized particularly for processing negative valence. In short, for stimuli presented in the LVF the RH was significantly more activated than the left for both affects but it was more responsive to sad relative to happy stimuli.

Bourne (2010) contrasted the two hypotheses but she also considered the emotions as being on a continuum of intensity, instead of discrete categories, using a chimerical faces test with 6 basic emotions chimeras (angry, disgust, fear, happiness, sadness and surprise). The study supported the Right Hemisphere Hypothesis, and all six emotions showed a RH bias. However, the strength of lateralisation within the RH varied across emotions. Similarly, Workman et al. (2000) tested the valence hypothesis using chimeras of all six of the basic emotions: happiness, sadness, anger, fear, pleasant surprise and disgust. They found a left visual field bias (RH advantage), which increased from happiness to sadness, pleasant surprise, disgust and fear to anger. Workman et al., suggested that as the LH is associated with communication and approaching behaviour, when the processing of pro-social facial expression comes into communication (which is RH lateralised) a shift towards the LH reduces the overall pattern of RH superiority

Therefore, whilst there is consensus of the leading role of the RH in emotion processing, the variability in strength of lateralisation of different emotions may suggest that the degree of hemispheric involvement in response to emotions may be mediated not only by approach/withdrawal but also the arousal component of emotion. Arousal is proposed to be orthogonal to valence and refers to a continuum ranging from excited to calm. For example, anger and sadness are both negative in valence, but anger is high in arousal, whereas sadness is low in arousal (Heilman, 1997). Dolcos et al., (2004) in an fMRI study investigated the effects of arousal and valence on emotion processing. They found clear topographic differences between valence-related and arousal-related components of emotional processing. While the valence effect activated frontocentral sites and ventromedial PFC, the arousal effect was evident at parietal sites and dorsomedial prefrontal cortex (PFC). Moreover, arousal has been shown to influence observed asymmetries in performance (Alfano and Cimino, 2008).

An alternative model proposed by Davidson (1992) is the valence–arousal model of emotion. This model is an integration of the RH and approach–withdrawal models. It proposes that RH prefrontal systems are biased toward negative valences, RH parietal systems are biased toward arousal, and left hemisphere (LH) prefrontal systems are biased toward positive valences (Heilman 1997).

Arousal affects various brain regions differently. In line with this, Killgore, & Yurgelun-Todd (2007) postulated that in the recognition of emotional expressions there are two interrelated systems in operation. Firstly, there is a dominant posterior RH system specialized in emotional recognition more generally, regardless of valence, but particularly well suited for processing the subtleties of negative affect. Secondly, a non-dominant posterior LH system with limited processing capabilities which involves valence-specific lateralised activation of orbito-frontal cortex and ventral striatum. The LH is therefore poorer in processing affect and here one might find a reason why it processes positive affect which is easy to identify. Killgore, & Yurgelun-Todd concluded that RH hypothesis and Valence hypothesis actually address separate interrelated components of the same system.

The research thus far considered the leading role of the RH in emotion processing, but also the variations in the strength of lateralisation for different emotions which could be accounted for by specialisation of the two hemispheres in the processing of the valence and arousal dimensions of emotions, as well as the approach and withdrawal behaviours which emotions elicit. In addition to focussing on the main theories for lateralisation of emotion processing in an effort to explain emotion recognition skills, it is also important to explore sex differences in lateralisation, especially as some research has indicated that females have a slight advantage in emotion recognition (Nowicki & Hartigan, 1988; Thayer & Johnsen, 2000).

1.5 Sex differences in laterality in adults

Sex differences in the degree of right hemisphere bias in emotional processing have been reported in the literature. Bourne (2005), for instance, explored sex differences in lateralisation for positive emotional processing and found that males and females had right hemisphere advantage when perceiving happy facial expression from chimeric faces, but males were more strongly lateralised than females who were more bilateral. The same significant right hemisphere bias Bourne and Maxwell (2010) found with all six basic emotions of happiness, sadness, angry, fear, surprise, and disgust. This pattern was found not only for biological gender (sex) but also psychological gender. The higher the psychological masculinity score the stronger was the right hemisphere bias for processing facial emotions.

Proverbio, Brignone, Matarazzo, Del Zotto, and Zani, (2006) investigated whether inconsistencies reported in the literature (RHH and VH support) are due to sex differences in hemispheric asymmetry. They supported Bourne's, (2005) finding in an ERP study where event-related brain potentials (ERPs) were recorded in right-handed women and men while they observed faces expressing different emotions. A strong right hemisphere bias was found in men whereas women showed a more bilateral functioning.

More recently Lin (2009) investigated differences in brain activation between males and females in an fMRI study. She reported sex differences in brain responses to fearful and sad faces: females had significantly more activation than males in amygdale while viewing sad faces versus neutral and this region was functionally connected with regions of both hemispheres. Males had greater activation in parietal regions of the right hemisphere to fearful than neutral faces. It seems therefore, that in females and males facial emotion processing is organised in different ways. The bilateral advantage in females might reflect an easier access to facial processes in both hemispheres and sheds light into female's superiority in processing facial emotion expression: Females are generally faster than males when they accurately identify facial emotions.

Sex differences were additionally found in an fMRI emotional memory study by Cahill, Uncapher, Kilpatrick, Alkire, and Turner (2004) and an ERP study by Gasbarri, Arnone, Pompili, Marchetti, Pacitti, Calil, and Tomaz (2006) with emotional stories. Cahill et al. reported a significantly stronger relationship in men than in women between activity of the right hemisphere amygdale and memory for emotional scenes judged as arousing, and a significantly stronger relationship in women than in men between activity of the left hemisphere amygdale and memory for arousing slides. Gasbarri et al. found that the emotional content of the story elicited a greater positive wave around 300ms, the P300, over the right hemisphere but in the left hemisphere emotional stimuli elicited a greater P300 in women compared to men. The effect was indexed by both amplitude and latency measures.

What the above studies might indicate is a more stable right hemisphere advantage for emotion processing in males and a more relative one for females that is determined by the source of affective information (faces as opposed to emotional scenes or stories), and hormonal levels. In fact, Geschwind and Galaburda (1985) proposed that sex differences in hemispheric asymmetry were observed due to the differential pre-natal hormonal exposure in males and females. They indicated testosterone as one factor implicated in the development of cerebral lateralisation and suggested that the higher levels of foetal testosterone in males can explain their stronger patterns of lateralisation.

1.6 Development of lateralisation for emotion processing

Research in the development of lateralisation in emotion processing has been scarce, only recently there have been studies to investigate the topic more systematically. Thus far, mostly behavioural measures have been used to investigate the development of laterality and the main measure used is the chimerical faces test (CFT).

There are differing views about the development of the laterality in emotional processing. Aljuhanay, Milne, Burt, and Pascalis (2010) for instance, investigated whether right hemispheric asymmetry in facial emotion processing is stable or increases across development in children between 5-6 and 10 years of age using a CFT with happy, sad and angry chimeras. They found right hemisphere advantage in the youngest 5 year old children but the degree of right hemisphere lateralisation did not change between 5 and 10 years. Similarly, Failla, Sheppard, and Bradshaw (2003), investigated age-related changes in perceptual asymmetries in the chimeric-faces task. They used four age groups, a younger 5-7 years old group, young 10-12 years old group, a middle 20-30 years old group and an older 60-70 years old group. They found a significant right hemisphere bias in the performance of the groups from 5-30 years of age which then attenuated so that the older group did not show this significant bias.

An alternative view to the one above is that lateralisation changes over childhood. Several studies suggested that while young children are lateralised for emotion processing, this lateralisation continues to strengthen until the age of 10 years when it reaches adult level. Levine and Levy (1986), in an early developmental study, using the chimeric faces test with happy chimeras, investigated the possibility that there are age changes in the degree of perceptual asymmetry in subjects ranging in age from 5 years to

17 years as well as elderly adults, 78 years of age. Levine et al. calculated a mean asymmetry score ranging from -1 which would indicate an absolute RH advantage and means that only pictures with a smile on the viewer's left were chosen as emotional), to +1, which would indicate an absolute LH advantage, which means that pictures with smile on the viewer's right were chosen as emotional. Findings showed that there was a well-established leftwards bias (Right Hemisphere advantage) for recognition of emotion by 5 years of age. However, the strength of the LVF preference (right hemisphere advantage) in youngest children was not as large as in the older age groups. In other words, there was an increasing RH lateralisation with age.

Similarly, Chiang et al. (2000) investigated the strength and direction of hemispheric asymmetries using CFT with children 6 to 16 year olds when they saw happy chimeric stimuli. They found a left visual field preference (right hemisphere advantage) which appeared to be present by age 6 and continue to develop until it was well established by the age of 10 years. After the age of 10 the advantage appeared to plateau.

More recently, Workman, Chilvers, Yeomans and Taylor (2006) investigated the development of laterality, using the six basic emotions of happiness, sadness, fear, anger, surprise and disgust in a chimeric faces test. They used three groups of children, 5-6, 7-8, and 10-11 years old and found that children from 5 years become increasingly lateralised for emotion processing but it is not until the age of 10 that children's lateralisation is comparable to that of adults. The mean chimeric face scores for all emotions combined showed that whilst the 5-6 age group had a score of 4 which indicated no hemispheric asymmetry, 7-8 and 10-11 year olds groups' score increased to a clear RH advantage. Interestingly, Workman et al. (2006) found that not only hemispheric asymmetry develops to a clear right hemispheric one with increasing age but that different emotions become lateralised at different ages. More specifically they found that recognition of happiness is right lateralised from an early age (5-6 years), laterality of sadness was marginally different between 5 and 10 year olds, fear has a higher laterality score in the 10-11 age group, surprise and disgust at the age of 7-8 years and anger at the age of 10-11 years. It is interesting that the order these emotions are lateralised to the right hemisphere, varies as does the order at which these emotions are recognised progressively by children across development as has been discussed previously in this review.

As a facial expression involves primarily a face, how do we know that the developing right hemisphere advantage is specific to the processing of the emotion in the face and not to face processing alone? Right hemisphere advantage for face processing in adults has been shown by a variety of studies across different methodologies (Chung & Thomson, 1995). But studies of hemispheric differences for face processing in children provided no support for an increasing right hemisphere advantage with age. In fact, Young (1983, 1986) reviewed all the relevant developmental studies at the time and came to a conclusion that right hemispheric asymmetry for face processing was established early in life (5 year olds were the youngest age tested in the studies reviewed) and the degree of asymmetry did not change but was invariant across the ages studied.

The question remains, whether the more lateralised to the right the children are, the better their emotion recognition from faces. Workman et al. (2006) and Watling and Bourne (2007) found a positive correlation between right hemisphere advantage and emotion processing skills. More specifically, Workman et al. reported that the degree of right hemisphere advantage (as reflected in the mean laterality score) was significantly positively correlated with the scores in two emotion processing tasks: the eyes test and situational cartoon task. As the right hemisphere asymmetry increases so did the emotional processing ability. Similarly, Watling and Bourne (2007) provided evidence that neuropsychological development underlies the development of emotion recognition skills. They reported an increase of the right hemisphere dominance in emotion processing with increasing age and a relationship between children's emotion recognition skills and the strength of lateralisation for processing emotions, for happy emotion. The more strongly lateralised to the right hemisphere for processing happy emotions children were, the more accurate were they in recognizing happy facial expression (Watling and Bourne, 2013, under review). They also found a relationship between laterality development and children's understanding of regulation of emotions in self-presentational interactions which emerged at the age of 10 years (Watling and Bourne, 2007)

In conclusion, developmental research has provided evidence of an association between children’s neuropsychological development and their better understanding of emotions. However, age differences in facial emotion recognition and hemispheric asymmetry in emotion processing have been supported by maturational changes in brain structures such as the corpus callosum. The development and function of these structures is the focus of the following section.

1.6.1 Maturation of brain structures: corpus callosum

There is agreement amongst researchers that the corpus callosum (CC), which is the largest neural pathway to connect the two cerebral hemispheres (Bloom and Hynd, 2005), plays an important role in the development of hemispheric asymmetry. The corpus callosum is a large neural band of fibres with more than 200 million nerve fibres. It is not a unitary body, rather it consists of many pathways or channels each responsible for transferring a distinct type of information making the inter-hemispheric communication and integration of information from the two hemispheres possible. This allows for a unitary sensory world as the two perceptual halves synchronise and fuse through the CC (Banich, 1998).

In addition to integration of hemispheric processing the question remains as to the role of the CC in the development of hemispheric lateralisation of function. This question was examined by Bloom and Hynd (2005). They reviewed the evidence for two contrasting theories of inter-hemispheric interaction which were debated in the literature: the inhibition and excitation theories. Inhibition theories postulate that the CC contributes to the development of hemispheric asymmetry by providing a pathway through which one hemisphere can inhibit the other and dominates for certain tasks such as language or emotion processing, whereas the excitation theory states that the CC enforces integration of cerebral processing between the two hemispheres and activates the un-stimulated hemisphere. According to the latter view the development of asymmetry is related to a lack of excitatory connection between the hemispheres. Bloom and Hynd (2005) found support for both theories that the CC can exert inhibitory and excitatory influences on the hemispheres.

The above findings support a model by Kinsbourne (1982) who stated that the CC is concerned with the excitation –inhibition balance in the brain rather than information transmission. This means that depending on the task at hand the CC will concentrate on one hemisphere or will distribute activation between hemispheres. Very relevant is the idea that as one hemisphere specialised for a task becomes overtaxed more resources are recruited from both hemispheres (bilateral advantage) giving an increased processing capacity. Therefore, even the less efficient hemisphere in a task than the other, has the capacity to contribute when task difficulty increases. This is in line with Banich’s (1998) report on performance in difficult tasks. Kinsbourne argued that without such equilibration, processing will “swing” from one hemisphere to the other.

The question arising is whether the “swing” is reflected in an established right hemispheric bias or bilateral processing of emotions over childhood and whether the equilibration is only attained by a developed CC. This could be the case as it known that the CC develops and the hemispheres of young children are more functionally disconnected than those of adults (Banich, 1998).

Giedd, Blumenthal, Jeffries, Rajapakse, Vaituzis, Liu et al. (1999) examined the effects of age on CC morphology and structural changes in a longitudinal study. They found that CC size continued to increase throughout adolescence and particularly the posterior areas. They suggested that the increased size reflects an increase in the myelination, indicating that the corpus callosum is one of the latest structures to myelinate. Along similar lines Keshavan, Diwadkar, Harenski, Rosenberg, Sweeney, and Pettegrew (2002) found an increase of CC size from 7 years until young adulthood and suggested that not only does this increase indicate the increased myelination but also an increase in the axonal size.

Hagelthorn, Brown, Amano, and Asarnow (2000) examined whether myelination and decreased transfer time would have behavioural consequences with physiological and behavioural measures; they obtained estimates of inter-hemispheric transfer time from visual event-related potentials (ERPs) acquired during performance of a matching task. This task examined the degree to which matching decisions were facilitated when two items to be compared were divided across the hemispheres rather than being directed to the same hemisphere (i.e., the degree of the bilateral field advantage). These researchers found clear evidence of a reduced bilateral field advantage with age and a trend indicating a reduction in inter-hemispheric transfer time based on the first negative wave in obtained ERPs.

Similarly, support for the view that a myelinated callosum is predominantly excitatory in nature facilitating inter-hemispheric transfer has been obtained by another developmental study. Fagard, Hardy-Léger, Kervella, & Marks, (2001) investigated the effect of the development of inter-hemispheric communication in bimanual coordination. They assessed inter-hemispheric communication by comparing the time of a manual response to a visual stimulus when the hemisphere perceiving the stimulus and the hemisphere controlling the manual response were the same (uncrossed condition) to the time when they were different (crossed condition) referred to as the Poffenberger paradigm (Poffenberger, 1912) . Two groups in two studies (5- to 10-year-old and 3- to 7-year-old children) were tested with a two choice response-time task, and a simple response-time task, respectively. In both studies, bimanual coordination was tested on a line-drawing task, and the performance on mirror and parallel movements was compared. The crossed–uncrossed difference decreased with age in both experiments, indicating that improved inter-hemispheric communication contributes to progress in bimanual coordination.

To summarise, the CC increases in size over childhood due to myelination of its axons. With maturation, CC maintains an equilibration in its function and arguably contributes to the development of hemispheric lateralisation of function supporting the behavioural findings reviewed above for the development of laterality. Further, a mature CC also allows for rapid and accurate inter-hemispheric transfers, making a process that is distributed across homologous locations between hemispheres more efficient. With an immature CC on the other hand, transfer is slow, resulting in unbalanced lateralised processes.

Despite evidence of a link between emotion lateralisation development and performance in different emotion recognition tasks, one question resulting from the above review is whether CC maturation and development bears any relevance to the developmental emergence and maturation of perceptual processes generally and whether the age at which lateralisation of a distinct process modulates the relationship between lateralisation and performance across the lifespan. This was addressed by Boles et al., (2008) who indicated that individual differences in maturation of CC at different ages of childhood can account for these relationships.

1.7 Asymmetry and performance: Boles', Barth's and Merrill's neurodevelopmental model

Boles, Barth and Merrill, (2008) investigated the relationship between lateralisation of processes and performance in tasks underlying these processes in a review of empirical studies. They adopted the modular view of brain development: different processes are independent in their lateralisation, therefore, lateralisation of different "modules" might develop at different ages and the relationship between lateralisation and ability may vary across specific processes and the ages at which the processes lateralise.

Boles et al. (2008), in a meta-analysis of 15 studies which used a variety of lateralised tasks and showed a significant asymmetry, found a U-shaped relationship between the age of lateralisation of certain processes, performance and the degree of asymmetry, irrespective of direction, left or right. Early- and late-maturing-lateralised processes in the reviewed studies showed positive correlations between performance and absolute asymmetry while processes lateralised and maturing in mid-childhood showed negative correlations with absolute asymmetry. For example auditory linguistic processes (measured with dichotic presentations of stimuli that have linguistic but not necessarily semantic content, for example digits and syllables) which appeared left lateralised at birth had a positive correlation between absolute asymmetry and performance (the more lateralised the better the performance). Similarly, the spatial positional process (presentation of a dot in one visual field and asking participants to state its location) which does not lateralise to the right hemisphere until late adolescence or young adulthood had also a positive correlation. On the contrary, the visual lexical process (words, multiple digits, or letters are presented to one visual field, or bilaterally and participants need to recognise them) which lateralises at intermediate ages between 8 and 11 years showed a negative correlation between absolute asymmetry and performance in adults (the more lateralised the worst the performance).

Boles et al. devised two possible mechanisms to account for the U shape relationship of age lateralisation, performance and absolute asymmetry: The maturity hypothesis and the developmental limits hypothesis. The former is based on individual differences in the rate of CC maturation and assumes, first, that an immature callosum results in a lateralised process (similar to Kinsbourne's "swing" stated above), while a more mature callosum results in a less lateralised but more efficient one and second, that developmentally advanced and developmentally delayed children are similar at the beginning and end of development of the callosum, but differ in the rate at which the end points are reached. It was shown by Pujol et al. (2004) that a group of developmentally delayed children lagged behind a control group in cortical myelination by 3.2 years. So advanced children develop a process at an age when their CC is less mature than do the delayed children, therefore, they are more lateralised than the delayed children and this early development translates to greater ability in adulthood. For processes lateralised later, in middle childhood, because CC is more mature in the advanced group this process should be less lateralised than in the delayed group and the relationship of asymmetry to performance should be negative in young adulthood. By late childhood the developmental curves of CC of the advanced and delayed children again asymptote together, with the result that asymmetry–performance correlations should again be positive as happens in early childhood

The developmental limits hypothesis postulates that the U shape finding is due to limitations in development which are different at different ages. In early childhood a limitation lies in the immaturity in the CC, in middle childhood the limitation is the loss of plasticity and in late childhood the limitation is the impoverished development.

The first restriction of immaturity has already been discussed in the maturation hypothesis: Processes that lateralise at an early age in advanced children develop at an age when their CC is less mature than the delayed children, therefore are more lateralised than in the delayed children and this early development translates to greater ability in adulthood. Therefore in adults, processes lateralised at this early age show positive performance–asymmetry correlations, because the most competent individuals have the most asymmetric representations of processes. The loss of plasticity in middle childhood is because delayed children develop the process at a later age, therefore their CC loses some of its plasticity resulting in having the processes represented asymmetrically in the brain. Advanced children, developing the process earlier, are not subject to loss of plasticity but at this age their CCs are more myelinated which produces more bilateral representations.

For processes that lateralise later in childhood the limitation is thought to be impoverished development. Especially the delayed children perhaps do not have the opportunity to develop such processes and they resort to simpler strategies and poor performance. Advanced children, on the other hand, develop the process and they develop it asymmetrically because of loss of plasticity of the corpus callosum, and they are competent at performing it. Therefore as adults, they show a positive correlation between performance and asymmetry.

Barth, Boles, Giattina, & Penn, (2012) tested the proposed relationship between the timing of a process maturation, lateralisation and performance in a study where they compared patterns of asymmetry for children (4-year-olds) and undergraduate students. More specifically they looked at the relationship between lateralisation for emotional (happy emotional CFT) and linguistic (dichotic listening word task) processing with performance on an emotion recognition and a word recognition task, respectively. For the linguistic processing task, which typically is lateralised to the left hemisphere in early childhood, children who were more strongly LH dominant in their processing performed better on the word recognition task. For adults the correlation between dichotic words accuracy and dichotic words asymmetry was not significant. For the emotion processing task, however, Boles et al., found that adults with greater right hemispheric asymmetry were more accurate in emotion recognition. For facial expression processing, therefore, where the lateralisation plateaus between 8 and 10 years (Chiang et al., 2000; Failla et al., 2003; Workman et al., 2006) they found the predicted by their model positive association between increased asymmetry and increased emotion recognition accuracy. For the children they did not find a correlation between asymmetry and performance. This could be perhaps because the model predicts the relationship between established asymmetry in adults and performance and is not relevant to the developing asymmetry.

Whilst the Boles et al. (2008) model does not predict the relationship between the asymmetry and performance in developing children, they pointed out two crucial aspects for laterality development: different processes may have different and independent developmental trajectories and the relationship between lateralisation and performance is defined by the age at which lateralisation occurs.

The interesting underlying point raised by Bole’s model is the mapping of behaviour to neural processes across the lifespan and the interplay between behaviour and age associated changes in the brain. This could be seen as a broader framework wherein to set the investigations into the links between emotion recognition skills with maturation of brain structures involved in the development of these skills, such as the right hemisphere.

1.8 Conclusions and Aims of the thesis

What the above literature review suggests is first, the right hemisphere has a dominant role in emotion processing in adults. It has been supported by numerous behavioural and neuroimaging studies. Second, the right hemisphere advantage in adults has been associated with better performance in emotion recognition tasks.

For children the literature review suggests that first, facial expression recognition skills develop gradually between 4 and 11 years of age with different facial expressions being recognised at different stages of development. The emotion recognition ability develops gradually for emotional facial expressions at 100% of intensity but also for emotions at lower intensities. Happy facial expression is first recognised followed by sadness or anger, then surprise or fear and finally disgust.

Second, right hemisphere lateralisation of emotion processing develops between the ages of 5 and 10 years with different emotions being lateralised at different ages. Third, there is a positive relationship between children's right hemisphere neuropsychological development and their better performance in emotion recognition tasks. The latter indicates that the behaviour is mapped to neural processes across the lifespan and there is interplay between behaviour and age associated changes in the brain.

Drawn on these conclusions the aims of this thesis is first, to explore the patterns of electrophysiological responses to facial expressions in adults and whether these patterns are lateralised.

Second, to explore whether the behavioural test of laterality, the CFT, can be validated as a test of laterality using electrophysiological measures (Study 1).

Third to investigate the patterns of electrophysiological responses to facial expressions in children from the age of 5 to 12 years and adults and explore at what age adults' responses develop and whether they become lateralised (Study 2).

Fourth to explore whether the laterality effect observed in the explicit behavioural CFT is also observed in passive viewing of chimeric faces (Study 2).

Fifth, to behaviourally assess the developmental changes of accuracy in facial emotion recognition tasks and changes of laterality for emotion processing of children over one year using longitudinal design (Study 3).

Sixth, to explore whether the development of strength of lateralisation for emotion processing predicts the development of the ability to accurately recognise facial emotions (Study 3).

Seventh, to explore the development of children’s ability to recognise facial expressions at differing intensities (Study 4).

Eighth, to explore laterality for emotion processing using an alternative measure of laterality, the DVF, and whether greater LVF bias predicts better performance in an emotion recognition task (Study 4).

1.9 Overview of the thesis

This thesis describes investigations into hemispheric asymmetry development and its relationship with different facial emotion recognition skills. To explore laterality, we examined electrophysiological responses in the right and left hemisphere using electrophysiological measures (ERPs) when children and a control group of adults viewed sad happy and neutral standard (full) faces and happy and sad chimeric faces. Additionally, we used behavioural measures of hemispheric asymmetry: the chimeric faces test (CFT) and divided visual field (DVF) paradigms. Using a longitudinal and a cross-sectional designs we explored which relationships existed between emotion recognition and laterality.

Chapter 2 provides a detailed description of the emotion processing methodologies and ERPs methodologies used.

Chapter 3 describes a set of two studies. Study 1aimed primarily to validate the chimeric faces task as a test of laterality using electrophysiological measures, (ERPs). Additionally, study 1 aimed to investigate the patterns of electrophysiological responses of early emotional processing at frontocentral sites and whether these become lateralised. Most importantly, it was expected that the ERP responses to the chimeras would reflect the visual field bias when processing facial emotions whereby chimeras with the emotion on the left or right visual fields would elicit different (asymmetric) ERPs across the two hemispheres. It was also expected to find the main ERP responses to facial emotions reported by previous EEG research and that there would be a RH advantage at some point within the first 400ms window of processing.

Study 2 aimed to investigate: the patterns of electrophysiological responses to early emotional processing at frontocentral sites, at what age these characteristic electrophysiological responses develop, whether they become lateralised, and the trajectories of this development. It was expected to find age-related changes in the ERP components indicated by existing investigations in typically developing children such as decreased amplitude with increasing age (Parker & Nelson, 2005).

Chapter 4 includes a set of two studies. Study 3 investigated longitudinal implications of children's emotion recognition skills and their developing hemispheric laterality. A longitudinal design was employed in order to assess the development of accuracy in facial emotions processing skills across a broad age range of children (5-11 years) but most importantly, the main aim of the study was to explore whether the development of right hemisphere processing of emotions from faces precedes or follows the development of the ability to effectively recognize facial emotions. Study 4 explored laterality for emotion processing with respect to children's sensitivity to emotion recognition employing a cross- sectional design.The aims of the study in this chapter were primarily to investigate how children's recognition of emotion at differing intensities may be affected by their tendency to process emotion is the right or left hemisphere. An alternative measure of laterality was used, the DVF paradigm. For assessing facial expression recognition skills an emotion recognition task and an emotion matching task were used with facial expressions displayed at three intensities (30%, 50% and 90%). A gradual improvement in accuracy with age and intensity was expected, but with distinct developmental patterns for each of the five emotions. It was also expected that differential sensitivity scores for different emotions and intensities would depend on the visual field of stimulus presentation.

In Chapter 5, all the studies and results are discussed in terms of both the behavioural and physiological evidence provided and how well this fits in with current research. In addition, it will discuss how the findings in this thesis can promote further our understanding of the hemispheric asymmetry for emotion processing, its typical development and how it characterises facial emotion abilities across childhood.

Chapter 2: Researching facial emotion recognition: Methodological considerations

As highlighted throughout the first chapter, the primary focus of this thesis is to explore the development of children's emotion recognition skills and how changes in the lateralisation of the brain for emotion processing may explain some of the variance and developments of these skills. To address the key aims of this research there are three key methodologies that will be used. The first is behavioural measures to assess emotion recognition, the second is behavioural measures to assess laterality, and the third is neuropsychological measures to assess laterality.

In considering what methods are most appropriate to address the research aims outlined in Chapter 1, one must consider what is known about the processing of facial expressions of emotion in the brain. Importantly, Bruce and Young’s (1986) cognitive model postulates that facial expression and facial identity are processed along two separate, yet interacting, pathways, whereby after an initial stage of visual structural encoding, expression can be processed regardless of identity and vice versa (Vuilleumier and Pourtois, 2007). The tasks used in the following set of studies are designed to go beyond the assessment of face processing and to assess the specific influence of emotion in recognition and processing.

This chapter focuses firstly on exploring how emotion recognition abilities were assessed with different emotion recognition tasks: emotion recognition task (ERT), emotion matching task, and identity matching task with different facial expressions. Secondly, assessments of laterality are explored: Divided Visual Field Paradigm and the Chimeric Faces Test (CFT). Thirdly, assessments of laterality using electrophysiological techniques are explored; event-related potentials (ERPs) from the electroencephalogram (EEG), using explicit and implicit emotion tasks. In this chapter the basic principles of the main methodologies will be described and evaluated, I will discuss how each of these methods will be implemented in this thesis, as well as provide details on the creation and validation of the stimuli that were used in all studies.

2.1 Assessing emotion recognition with behavioural measures

The majority of research studies exploring emotion recognition use behavioural tasks of emotion recognition. More specifically two main tasks have been used in the facial emotion recognition development research: identification tasks and perceptual discrimination tasks. These tasks assess conceptual and perceptual processes, respectively. Furthermore, participants attend to different levels of face characteristics (i.e., global/holistic and featural/analytical) when perform facial expression identification and discrimination tasks (Gagnon, et al., 2010).

Identification tasks are designed to examine a participant's conceptual knowledge of emotion; specifically it assesses whether participants recognise an expression as belonging to the category of a specific emotion (e.g., happy, sad, angry). Identification involves comparing the configural characteristics of a face with the internal representation of a prototype expression of a facial expression of emotion. Greater accuracy in emotion identification and discrimination means, therefore, an improved quality, and refining of the prototype of each specific category or emotion. Gagnon et al. (2010) and Widen and Russell (2003) used identification tasks to reach the incremental conceptual differentiation hypothesis: emotion categories gradually emerge by refining previously acquired concepts of broader categories of emotions (see chapter 1). Two common emotion identification tasks are the emotion discrimination and emotion recognition tasks. They both require children to retrieve the conceptual knowledge of an emotion indicated by a label and compare it and match it with a facial expression. More specifically, in the emotion discrimination task, participants are shown a pair of faces and they have to point to the face in each pair which expresses a target emotion. In the emotion recognition task, a face is presented centrally and children have to decide whether the face expresses a specific emotion in a forced choice manner (happy/not happy). As discussed in chapter 1, researchers using differing tasks report slightly different ages at which different emotions are recognised. One example is Vicari et al. (2000) who examined the development of emotional facial recognition skills using an emotion matching and an emotion recognition tasks. In the emotion recognition task they found high accuracy in 5 year olds for happiness and sadness. For disgust, surprise and fear significant improvement was seen between the ages of 5 and 10 years. In matching task happiness, disgust and surprise were matched accurately in 5-year-olds but for anger and fear children significantly improvement between the ages of 5 and 10. Nevertheless, the study showed similar developmental trajectory of emotion recognition ability for different emotions with other studies (see section 1.2)

Perceptual discrimination tasks, investigate the ability to visually discriminate basic emotions from one another. There is a categorical representation where participants compare the features in one facial expression to the features of a second image of a face and then make a “same” or “different” judgment. This type of task can be an explicit emotion recognition task, where the participant is asked to match emotional expressions, or an implicit emotion recognition task, where the participant is asked to match identity but the emotional expression is varied. For the explicit version of the task, a trial typically involves the participant being shown one face (the target face) and asked to judge which of two faces below the target face expresses the same emotion as the target face, all shown simultaneously. Matching of facial expressions of emotion involves analytical processing and becomes more complex when the two facial expressions are similar (e.g., fear and surprise). In other words, similarity of the facial expression (facial configuration) increases the difficulty of the task (Bruce et al., 2000), whereas distinctiveness of the faces increases (De Sonneville et al., 2002).

For the implicit version of the task, a trial typically involves the participant being shown one face (the target face) and asked to judge which of the two faces below the target face the same person as the target is. The key to the implicit task is that the target face and the correct response express different emotions; therefore, the participant must ignore the emotive information and focus on identity matching. Herba et al. (2006) suggested that the distracting effect of emotion on an identity matching task is an index of neural correlate of emotion processing since the implicit processing of emotions is linked to amygdala and prefrontal cortex development (also see section 2.3.4, this chapter). Performance, therefore, depends on the quality of visual discrimination, emotion decoding skills from faces, and analytical face processing skill as well as the development of emotion specific structures such as amygdala and prefrontal cortex.

Furthermore, researchers have created more demanding versions of these tasks (in terms of visual attention and information retrieval demands) by using facial emotions displayed at different intensity levels (Castelli, 2005; Herba, et. al. 2006, Kotsoni, et. al. 2001). Each emotion at 100% of intensity is digitally morphed with neutral expression, to represent different intensities of an emotion being present (e.g., 30%, 50%, 70% and 90%). For example, a 30% happy morph is made by 30% of happy expression and 70% of neutral expression, a 60% happy morph is made by 60% of happy expression and 40% of neutral expression. In analysing performance, the researcher can examine thresholds for emotion recognition, with neutral and emotion at the extremes of a continuum and the point in the continuum where the emotion is recognised is considered the category boundary for the emotion and for a particular age (Kotsoni, et. al. 2001).

In this thesis, four common emotion tasks were used, which included an identification task (emotion recognition task), and three perceptual discrimination tasks (emotion discrimination, emotion matching, and identity matching). The perceptual discrimination tasks were adapted form Bruce et al. (2000). These tasks were chosen to be appropriate for children 5 to 11 years old, and to provide varying levels of difficulty.

Emotion Recognition Task. The stimuli used in this task were created by greyscale images from the NimStim Set of Facial Expressions of (NIMH) of 43 professional actors (males and females) which were validated as good exemplars of five basic emotions (happy, sad, fearful, angry and surprised) and a neutral face (see section 2.4.1).The size of the NimStim stimuli was manipulated and the sizes used subtended approximately 8.5° horizontally and 12° vertically. The stimuli were framed with a black oval mask to remove additional features such as hair and ears. All faces were posed in full frontal orientation. Facial expressions of all five emotions (at 100% of intensity) were morphed, using Abrosoft FantaMorph 4.2 software, with neutral expressions of the same actor to create three intensity levels for each emotion (30%, 60% and 90%). The stimuli were presented centrally using Runtime Revolution 3.0 software. They were presented in blocks one for each emotion. In each emotion block there were 6 faces of the target emotion presented at three intensities each, and 2 faces of each of the other non-target emotions randomly chosen by the Revolution programme. In total there were 16 trials in each block. A fixation cross was presented at the centre of the screen for 500ms which was followed by a face which was presented for 1500ms, at the centre of the screen. The participants were instructed to maintain central fixation during stimulus exposure. After the face went away a blank screen appeared very briefly as a backward mask and the question whether the face was happy or not happy, sad or not sad depending on the block, appeared and remained on the screen until a response was made (Figure 2.1). Accuracy was recorded by the Runtime Revolution programme. Children received a score of 1 for a hit and correct rejections (clicked the “emotion” button when there was an emotion, or when they clicked the “not emotion” when there was not the target emotion) or 0 for a miss, and false alarms (clicked the “not emotional” when there was the emotion, or clicked “emotion” when there was not the target emotion.

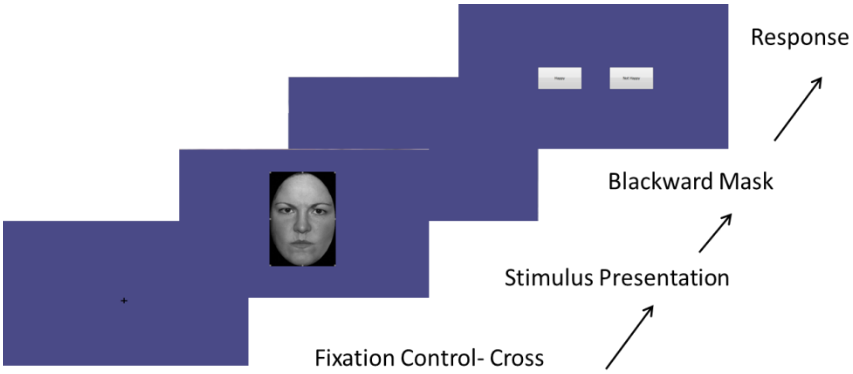

Figure 2. 1. Emotion Recognition Task: The protocol of events in each trial.

Emotion discrimination task: The stimuli used in this task were the same used in the above task (greyscale images from the NimStim Set of Facial Expressions of (NIMH)). In this task children were presented with a pair of full faces of the same gender. One face in the pair depicted one of the six facial expressions as a target emotion (happy, sad, angry, fear, surprise and neutral) and it was paired with a different distracter non-target emotion. Participants were asked to choose the face expressing the emotion specified to them at the beginning of the trial (Figure 2.2). Responses were recorded by the Runtime Revolution programme. Children received a score of 1 if they clicked the correct response or 0 if they clicked the wrong response. In total there were 36 trials, 6 trials for each facial expression (3 trials had a male identity and three a female identity). In 17 pairs the two faces were of the same identity (for increased difficulty) and 19 were of different identity (easier trials). In version 2 of the task, the reverse was seen: 19 were of the same identity and 17 were of different identity.

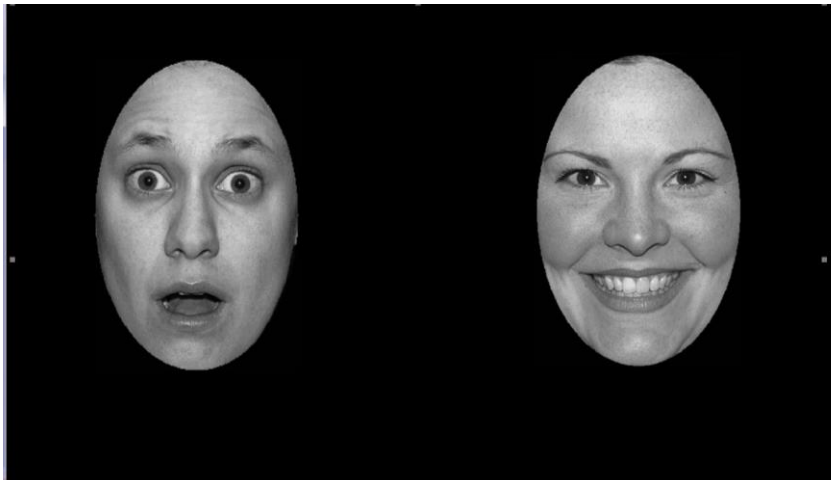

Figure 2. 2. Emotion Discrimination Task: Example of a trial (different identities).

Explicit emotion-matching task: The stimuli used in this task were the same used in the above tasks (greyscale images from the NimStim Set of Facial Expressions of (NIMH)). The faces subtended approximately 6° horizontally and 8.5° vertically. This task was used in two versions. The first one (used in longitudinal study 1, chapter 4) used stimuli expressing 100% of intensity of the five basic emotions and neutral. The second version (used in study 2, chapter 4) used the stimuli expressing three intensities of each of these emotions (30%, 60% and 90%). The general procedure of the task is the same for both versions (for details in each one, see section 4.1.1 and section 4.2.1). In this task, the sex of the stimuli always match (Bruce et al., 2000; De Sonneville et al., 2002). Therefore, the target stimulus was of the same sex as the two choice stimuli. Participants were asked to match the emotion of a target stimulus presented at the centre top of the computer screen with one of two choices presented at the bottom of the screen (Figure 2.3). Accuracy was recorded by the Runtime Revolution programme.

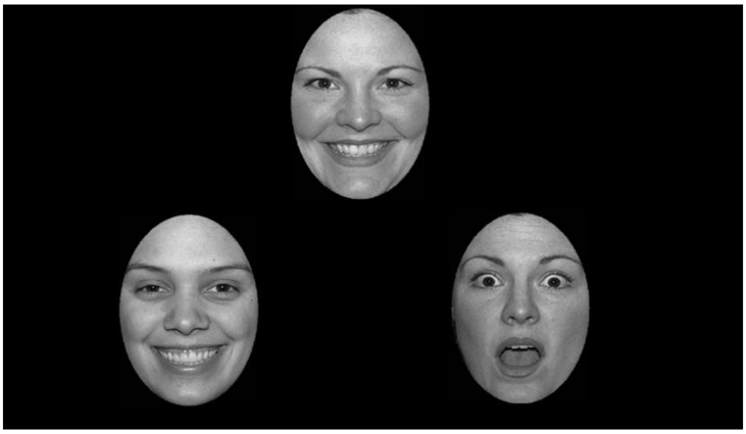

Figure 2. 3. Emotion Matching Task: Example of a trial (the face on the left is the correct matching).

Implicit emotion-matching (identity matching) task: The stimuli were the same and of the same size as in the emotion matching task above with the sex of the stimuli always matching (Bruce et al, 2000; De Sonneville et al., 2002). There were a total of 22 trials. There were 11 male and 11 female identities, which when they were the correct choice were posing five emotions. Half of the trials had the correct choice on the left bottom side and half had the correct choice on the right bottom side. All images were of the same size subtending approximately 6° horizontally and 8.5° vertically. The order of trials was randomised by the computer programme. Three faces were presented on the screen. One at the top centre was the target stimulus with neutral expression and two faces at the bottom left and right of the screen were the choice stimuli. One of the choice stimuli was of the same identity to the target stimulus, but with a different facial expression from the target stimulus, therefore the emotional expression was used as distracter to identity matching. Participants were asked to match the identity of a target stimulus presented at the centre top of the computer screen with one of two choices presented at the bottom of the screen (Figure 2.4). In essence, children were required to ignore the emotion, and to match the identity (in Figure 2.4 the face on the right is the correct response). Identity matching with different facial expressions is an implicit emotion processing task and it involves ignoring the emotive information and focus on identity matching. Accuracy and reaction time measures were recorded by the Runtime Revolution programme. Children received a score of 1 if they clicked the correct response or 0 if they clicked the wrong response.

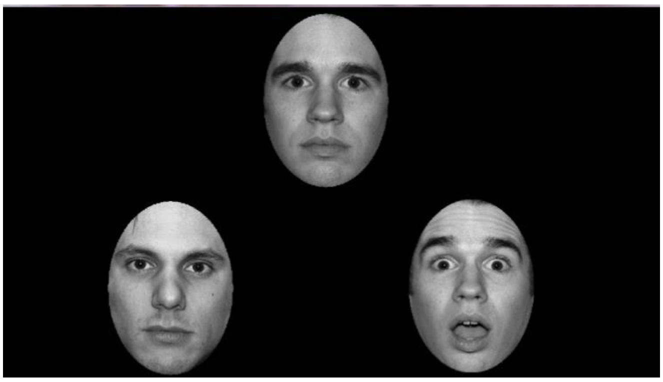

Figure 2. 4. Identity Matching Task: Example of a trial (the face on the right is the correct matching).

2.2 Assessing laterality with behavioural measures

Hemispheric laterality for emotion processing has been assessed using a variety of behavioural methods over the years. For instance, images have been presented tachistoscopically (e.g., Heller & Levy, 1981; Reuter-Lorenz & Davidson, 1981); free viewing with the Divided Visual Field paradigm (e.g., Jansari, 2000, 2011; Roadway, Wright & Hardie, 2003), and with a free viewing centrally presented chimeric faces task (e.g., Bourne, 2005, 2006, 2008; Levine & Levy, 1986; Workman, Peters & Taylor, 2000). With new computer technologies for aiding the presentation of stimuli the more common measures are the divided visual field and chimeric faces test to assess hemispheric asymmetry, and these two tasks will be discussed in the following sections.

The behavioural tasks of laterality are based on the crossed nature of the visual system which projects information from one half visual field directly to the opposite hemisphere. The visual system is organised in a way that cells located in the area of retina nasal to the fovea send their axons to the contralateral optic tract, and cells located temporal to the fovea send their axons to the ipsilateral optic tract. Therefore, stimuli received by the nasal hemiretinae are projected to the contralateral hemisphere, whereas stimuli received by the temporal hemiretinae are projected to the ipsilateral hemisphere (Bourne, 2006; Stone et al., 1973).

Before exploring the assessment of laterality for emotion processing, it is important to note that when assessing hemispheric asymmetry there is one common confound that must be controlled for; this is the handedness of the participant. Whether the participant is right-handed, left-handed or ambidextrous has been shown to be related to how the brain is organised and could influence responding. In fact, researchers have found handedness influences laterality for language processing, visuospatial processing, and emotion processing.

2.2.1. Lateralisation in the brain and handedness

When considering lateralisation it is important to include participants with patterns of lateralisation consistent and representative of the population (Bourne, 2006). One such group is the right handers. Several studies have reported consistent patterns of hemispheric asymmetry in right handers in lateralisation of language more so than the left handers. In comparison to right handers, left handers appeared to have more variable pattern of lateralisation. More specifically, Pujol et al. (1999) in an fMRI study looked at brain activation during silent word generation in left- and right handers. They found that 96% of the right handed participants had the standard LH dominance for language function but this percentage was reduced to 76% in left-handed participants. Similarly, Floel et al. (2005) in a Doppler (fTCD) ultrasonography study of word generation task reported that the right-handed participants showed left-hemispheric language dominance in 97% of cases whilst left-handers showed left hemispheric language dominance in 74% of cases. Comparable differences between right and left handers were found in other studies with other methodologies. Bryden et al. (2006a) in a dichotic listening task found left hemisphere lateralisation for language processing in 80% of right-handers but 70% of left handers. Lavidor et al. (2003) tried to determine the relationship between word recognition and lateralisation in a dichotic listening task and a divided visual field task. Right handers' responses to words were faster when presented in the right ear and left handers were faster to respond to words when presented in the left visual field.

In addition to lateralisation of processing on language tasks, which report the more standard left hemisphere advantage for right handers and more variable pattern of lateralisation for left handers, researchers have found similar differences depending on handedness for visuospatial processing. Visuospatial processing is a right hemisphere lateralised process. Fink et al. (2001) in an fMRI study explored adults visuospatial processing using the landmark task. They found that in comparison to left handed participants, right handed participants had greater bias and perceived the subjective midpoint of a horizontal line to be to the left of the objective midpoint, thereby indicating right cerebral hemisphere activation due to the visuospatial nature of the task. Similarly, Cicek et al. (2009) in an fMRI study assessed hemispheric bias to attention allocation using the line bisection and the landmark tasks. They found right handers showed greater leftwards bias in the tasks. These findings were supported in a meta-analysis by Jewell and McCourt (2000) which found that handedness affects visuospatial processing in line bisection tasks, with right handers having this leftward bias greater than the left handers.

With regard to emotion processing there is some evidence showing that right and left handers appear to have different asymmetries. For example Bourne (2008) found a positive relationship between degree of handedness and degree of cerebral laterality for emotion processing whilst Reuter-Rorenz, Givis, and Moscovitch (1983) showed that non inverted left handers (did not have inverted handwriting posture) had a reverse pattern of valence asymmetry from right handers and inverted left-handers. The right handers and inverted left-handers were faster to identify happy faces presented in the RVF and sad faces presented in the LVF. Additionally, Everhart, Harrison and Crews (1996) found different patterns of lateralisation. In fact left handers tended to identify a neutral face as happy when presented in the LVF but had a bias to rate neutral faces more negatively when presented in the RVF. On the contrary, Van Strien and van Beek (2000) found that handedness did not affect the ratings of emotional expressions expressed by cartoon faces. Therefore, whilst right handers overall show a more consistent right hemisphere bias, for emotion processing, than left handers conflicting evidence renders the issue far from resolved. One way to explain the differences reported between right and left handers is by looking at the differences in cortical organisation that affect the processing of emotions (Everhart et al., 1996). Most researchers control for strength of handedness by using only right handers or have a balance of right and left handed participants (Roadway, et al., 2003).

Assessing handedness

Handedness can be assessed using a handedness questionnaire. There are two key handedness questionnaires that are commonly used which aim to assess which hand, or the extent to which one hand, is used by adults for common everyday tasks. One quite frequently used questionnaire is the Edinburgh Handedness Inventory (Oldfield, 1971). This consists of 10 items, questions about participants' practice in common daily tasks (e.g., writing, drawing, brushing teeth). For each item participants have to make a binary response (use left hand or right hand) to indicate which hand they use to perform the task. A participant performing eight or more tasks with their right hand would be considered strongly right-handed and where there was concern and desire to only use right handed individuals these participants would be suitable for inclusion in a study of laterality. The Edinburgh Handedness Inventory approaches handedness dichotomously. Another approach is to measure handedness in a continuum. Dorthe et al. (1995) developed a handedness scale that used a 7-point Likert scale with preference scores ranging from -3 (''Always with left hand'') through 0 (''Equal or no preference'') to +3 (''Always with right hand''). This scale allows handedness to be scored on a continuum, which is consistent with measures of cerebral laterality that are also often measured on a continuum. Assessing handedness on a continuum specifically enables the associations between the degree of lateralisation and the degree of handedness. Some studies, however, select only right-handed participants by self-report (Rodway et al., 2003). Most of the studies of emotional processing reviewed in this thesis have used right handed participants by self-report as an initial selection procedure, but this was also backed up with other assessments of handedness.

In this thesis, adults completed handedness questionnaire by Dorthe et al. (1995). This questionnaire was comprised of 17 items, each measured on a seven-point Likert scale form -3 (always with the left hand) to +3 (always with the right hand). The scores were summed to obtain a handedness score ranging from -51 (strongly left handed) to +51 (strongly right handed). Participants who reported being right handed had a mean score of 37.7, SD (5.7), range from 28 to 51. For children, aged 5 years to 11 years, there were three practical tasks that were used to assess handedness. Children were presented with a piece of paper and asked to write their name on this and then to cut the paper in half so another child could use the other half (note another child did not use the second half of the paper, but it was just to give reason to the task). Finally children were seated in front of a computer and provided with the mouse centrally positioned. All responses to the task were by using the mouse. The experimenter documented which hand each participant used to write his or her name, to cut the paper, and to use the mouse. If for all three tasks the right hand was used, the child was considered right handed and their results were included in the analyses.

2.2.2 Chimeric Faces Test (CFT)

The chimeric faces test (CFT) is a widely used behavioural measure of emotion lateralisation; its simplicity and brevity enables large-scale laterality investigations (Levy et al., 1983). As discussed in section 2.2, it is based on the crossed nature of the visual system which projects information from one half visual field directly to the opposite hemisphere. A stimulus presented in the left visual field (LVF) is processed by the Right Hemisphere (RH) and a stimulus presented in the right visual field (RVF) is processed by the Left Hemisphere (LH), (Beaumont, 1983). The CFT uses chimeric faces. They are made from two faces in greyscale, showing a static frontal image of the face. One of the faces has a neutral facial expression and one has an emotional expression. These two faces are then split in half vertically. The emotional hemifaces are then attached to neutral hemifaces. The left half of the chimeric face shows an emotional expression (happy, sad, angry), and the right half shows a neutral expression from the same poser. This was the original chimeric face. Two copies of a face were presented in each trial, one above the other. One of the faces showed the emotional expression in the left hemiface (the original) and the other showed the emotional expression in the right hemiface (the mirror image of the original). The processing of chimeric faces tends to show an advantage of the left hemiface because of the aforementioned cross nature of the visual system, whereby information from the viewers' left visual field is initially received and processed by the right hemisphere (Ashwin et al., 2005; Bourne, 2005, 2008, 2010, 2011; Christman and Hackworth, 1993; Levy et al., 1983).

There are two versions of the task: one uses a pair of faces, and the other uses just one chimeric face.

In the first version, the chimeric faces in the CFT are presented centrally in pairs, one original with the emotion on the left side from the viewer's point of view (left visual field or left hemifield), and its mirror image, which shows the expression in the right side from the viewer's point (right visual field or right hemifield). The two faces of the pair are presented one above the other. Each pair is presented twice. Once with the original chimeric face (emotion in the LVF) at the top and its mirror (emotion in the RVF) at the bottom and once with the faces presented in the reversed place (mirror at the top and original at the bottom). The participants are asked to decide which of the two faces of the pair is more emotive. If participants select the chimera with the emotion in the left as more emotive, it reflects a RH advantage in the processing of the emotional information. On the contrary, if the chimera with the emotion to the right of the viewer is selected it means that the LH has the leading role of the processing of the emotion, according to the aforementioned crossed nature of the visual system. The CFT was initially introduced by Levy et al. (1983). The scoring of the test is typically based on visual field response bias. Specifically, bias is assessed as the number of times participants chose the more emotive face as the face that expresses the emotion in the left visual field from the viewer’s side versus the number of times participants chose the more emotive face as the face that expresses the emotion in the right visual field from the viewer’s side. Whilst some studies calculate the bias in terms of the number of visual field responses or percentage of the visual field responses (e.g., Bava et al., 2005; Burt & Perrett, 1997; Chiang et al, 2000), other studies from participants’ responses calculated a laterality quotient (e.g., Bourne, 2005, 2008, 2010, 2011; Failla et al., 2003; Levine & Levy, 1986). Laterality quotient is a score that ranges from -1 to +1. It is calculated by the following formula: number of responses to the LVF - (number of total trials - number of responses to the LVF) / number of total trials. Negative scores indicate that participants chose faces in which the emotion is expressed in the viewer’s right visual field more often than when the emotion is expressed in the viewer’s left visual field, thereby suggesting a left hemisphere dominance for the task. Positive scores indicate a preference for faces in which the emotion is expressed in the viewer’s left visual field than when the emotion is expressed in the viewer’s right visual field, thereby suggesting right hemisphere dominance for the task.

In the second version a single chimeric face is presented centrally with a visual analogue scale below it showing “Not very happy” on the left end of the scale and “Very Happy” on the right end. Participants have to show on the scale how happy they think the face is. Mean happiness ratings are calculated for the left and right half face stimuli. The difference between these gives a laterality bias, with positive values reflecting LVF bias (higher happiness ratings for the face with happiness expressed in the left half face) and indicating a right hemisphere bias (Bourne and Gray, 2011). The one face chimeric faces test has been used by Kucharska-Pietura & David, (2003). They showed centrally a single chimera expressing happiness in the one hemiface and sadness in the other hemiface. Participants were asked to report the emotion being expressed. They found that participants tended to base their responses on the emotion expressed by the left hemiface, reflecting a right hemisphere processing advantage.

Bourne and Gray (2011) directly compared the laterality biases found in the two versions. They found a correlation between the laterality biases which suggests that the two versions measure the same bias. However, they found that the two face version was more reliable than the one face version of the CFT. In the set of studies within this thesis the two faces version of the CFT was used.

The CFT has been validated by Kucharska-Pietura and David (2003) as a test of laterality for emotion processing. In their study they compared the judgments on chimeras of a group of individuals with either left or right hemisphere brain damage, and a healthy control group. They found a left visual field bias (RH advantage) in both the controls and the patients with unilateral left hemisphere lesions, when judging chimeric faces but patients with unilateral right hemisphere lesions showed a significantly reduced left visual field bias. Similarly, Bava et al. (2005) reported the same bias in children with unilateral congenital brain damage.

The task in this thesis was administered in the same way as previously reported by Bourne (2005, 2008, 2010, 2011; Workman et al., 2006) in a computerised form. Children were presented with pairs of chimeric faces, centrally, one above the other (Figure 2.5). The stimuli were happy, sad and angry chimeras. They were created by greyscale images from the NimStim Set of Facial Expressions of (NIMH) of 43 professional actors (males and females) which were validated as good exemplars of five basic emotions (see section 2.4.1). The size of the NimStim stimuli was manipulated and the pictures subtended approximately 6.5° horizontally and 9° vertically. In each chimera the half of the face in the left visual field showed an emotion (happy, sad, angry) whilst the other half in the right visual field was neutral. The second face in the pair was the mirror image of the first face showing a neutral expression in the left visual field and an emotion in the right visual field. There were 24 trials for each emotion and presentation was randomized within each block. This number of trials was considered satisfactory by Levy et al. (1983) and is consistent with what other researchers have used (Bourne, 2005; Watling and Bourne, 2007). Children were asked to concentrate on the faces and decide as fast as they can which they thought looked happier, sadder or angrier and click on their choice. The images remained on screen until a response was made. During the presentation of the stimuli, a cursor was positioned in the middle between the two faces. In that way any upward movement of the cursor would enable children to click on the top face and any downward movement would enable them to click on the bottom face. From their responses a laterality quotient (CFT-LQ) was calculated ranging from -1 (always choose the emotion in the right visual field indicating left hemisphere advantage) to +1 (always choose the emotion in the left visual field, indicating right hemisphere dominance).

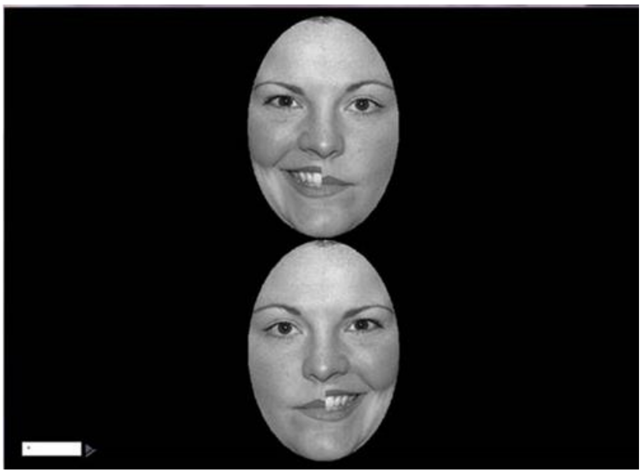

Figure 2. 5. Presentation trial of the CFT.

2.2.3 Divided Visual Field Paradigm

While most studies in this thesis use the chimeric faces, it was important to also include an alternative measure of laterality for emotion processing. The Divided Visual Field (DVF) methodology in facial emotion research explicitly examines the functional hemispheric asymmetries of emotional processing in an easy, accessible and effective way (Lindell & Nicholls, 2003). Similarly to the CFT, the DVF is based on the crossed nature of the visual system which projects information from one half visual field directly to the opposite hemisphere. A stimulus presented in the left visual field (LVF) is processed by the Right Hemisphere (RH) and a stimulus presented in the right visual field (RVF) is processed by the Left Hemisphere (LH). There are some crucial methodological considerations for successful implementation of the visual half-field technique and these will be described below: the protocol of events, fixation control, unilateral presentation of stimuli, measures and analysis. This task is therefore a good alternative to the CFT.

Protocol of events

It is important that a participant's head is stable to restrict movement and that it is positioned at a constant distance from the monitor by the use of a chinrest; this controls the visual angle of the stimulus presentation. Bourne (2006) recommends four main events in each trial of the DVF methodology with adults: the first is the fixation to ensure that the participant is fixating centrally before the stimulus is presented, the second is the presentation of the stimulus, the third is a backward mask of the stimulus, and the fourth is the participant's response.

In the DVF methodology the stimulus must be presented at a specified distance from a central fixation point. It is therefore crucial to control where the participant is fixating when the stimulus is presented to ensure that it is presented in the correct part of the visual field. One simple indirect method of fixation control is instructing the participant to fixate centrally on a specified fixation point. Ideally, one could monitor eye movements and stimulus presentation using either eye-tracking equipment or electrooculogram. This is not always possible so the method of the experimenter monitoring the central fixation of participant is recommended as effective (Bourne, 2006). Another requirement of the DVF paradigm, in order to achieve unilateral presentation is the placement of the stimulus in the visual field and its duration of exposure. The precise placement of the stimuli in the visual field is defined by the neuroanatomy of the visual system (discussed in section 2.2). The crossover in the commissural connections of the corpus callosum, results in a certain amount of overlap (1° wide strip) between the visual fields. In order to achieve unilateral presentation, it is important to present stimuli outside this region of overlap. However, there has been some disagreement as to where precisely stimuli should be presented. Previous papers have recommended that a stimulus be presented with the inside edge at least 2.8° to up to 3.8° from central fixation (Bunt et al., 1977; Young, 1982). In a synthesis of earlier work, Bourne (2006) recommends presentation of a stimulus with inside edge 2.5°-3.8° from central fixation. Unilateral presentation of the stimulus is maintained when it is completed before an eye movement towards the stimulus occurs (saccade). Saccades are rapid, ballistic eye movements that move the fovea (the region of highest visual acuity) towards the stimulus and with a latency of 150ms to 200ms for adults (Carpenter, 1988). The stimulus presentation for adults, therefore, needs to be completed within 150ms in order to minimise the possibility of a saccade to the stimulus, which would then result in the stimulus being presented bilaterally rather than unilaterally. Bourne (2006) recommended that stimulus presentation is limited ideally to 150ms but can be expanded to a maximum exposure of 180ms.

Stimulus presentation in the DVF needs to be counterbalanced, whereby the visual field in which the stimulus is presented cannot be predicted. Counterbalancing the side of presentation following the fixation reduces the opportunity for anticipatory saccades (saccades towards the stimulus when its location is predictable and which have latencies less than 100ms; Bourne, 2006). Additionally, immediately following the presentation of the stimulus it is important to have a backward visual mask. After stimulus presentation, the participant may experience afterimage effects (their own subjective afterimage or, for some monitors, caused by phosphor persistence) which effectively extend the presentation duration beyond the desired one and in an uncontrollable manner. A backward mask reduces the chance that such afterimage effects will occur and ensures that the exposure duration of the stimulus is controlled (Bourne, 2006; Enns & DiLollo, 2000). For our study, the backward mask was a blank screen which followed the stimulus presentation for 100ms. Typically, two types of data are collected from DVF experiments: speed and accuracy. In paradigms that use a forced choice binary decision, all responses are categorised into four types: a hit, when participants detect the target stimulus as being present, a correct rejection when participants correctly respond that the target stimulus is not present, a miss when they fail to detect the target as present and a false alarm when they incorrectly respond that the target stimulus is present when it is not. In the case of a binary forced choice task, the signal detection theory measure of d’ takes into account all four possible responses, (Swets, Dawes, & Monahan, 2000). Subsequently, the reaction times are calculated for each of the four types of responses which within each condition are then summarised by calculating the mean reaction time in that condition. The data acquired from DVF experiments is most often analysed using analysis of variance (ANOVA) (Bourne, 2006).

There is one study, to our knowledge, that used the DVF with children. Koenig, Reiss and Kosslyn (1990) used the DVF paradigm with children 5 to 7 year olds using a categorical spatial task, where they had to report whether a dot was above or below a short horizontal line and also determine whether a dot was within 3 mm of the line. They found a LVF bias for the second, the distance task, and a RVF bias for the first, above/below task. This demonstrates that the DVF is appropriate with 5-year and older children.

Importantly with adults’ emotion processing, there are studies that have reported a LVF (RH) bias in accuracy as well as reaction times measures irrespective of valence (Tamietto et al., 2005) or have reported a LVF bias for negative emotions and RVF bias for positive emotions (Jansari et al., 2000; Jansari et al., 2011; Reuter-Lorenz and Davidson, 1981; Roadway et al., 2003). For a review, see chapter 1.

Measures of a DVF task

The procedure used in the present thesis is identical to the one described above for adults with the following exceptions: First, we added a fifth event in the protocol which was a cartoon subtending approximately 3.5° horizontally and 3.5° vertically. This was presented after the fixation cross for 250ms centrally, and was aimed at helping participants maintain fixation centrally before the presentation of stimulus. Second, the duration of the stimulus presentation was 250ms. This was considered long enough to permit participants to see the stimulus bilaterally but short enough to minimise the possibility of a saccade to the stimulus. Third, training was provided to ensure children understood how to fixate: before the study started, a “game” with children trained them to fixate at an object centrally in front of them and report numbers shown to them in their visual periphery by the researcher. Fourth, as children were seen in groups of two, the researcher was able to monitor their fixation.

All images used in the DVF of this thesis were of the same size, subtending approximately 8.5° horizontally and 12° vertically. Participants were instructed to look only at the fixation cross and the cartoon at all times, without moving their eyes. The left or the right visual field presentation of the stimuli was counterbalanced and randomised by the computer programme. Each trial began with a fixation cross presented at the centre of the screen for 500ms, followed by a small cartoon (for attention catching and help in fixating at the centre) which was presented for 250ms. The cartoon disappeared and a face (with an emotion at 30%, 60% and 90% of intensity) was presented for 250ms, with the inside edge 2.5° from central fixation, on the left or the right of the fixation cross. After the face stimulus disappeared and the backward mask, a question whether the face was “Happy” or “Not Happy”, “Sad” or “Not Sad,” etc. appeared which remained on the screen until a response was made. Accuracy was recorded by the Runtime Revolution programme.

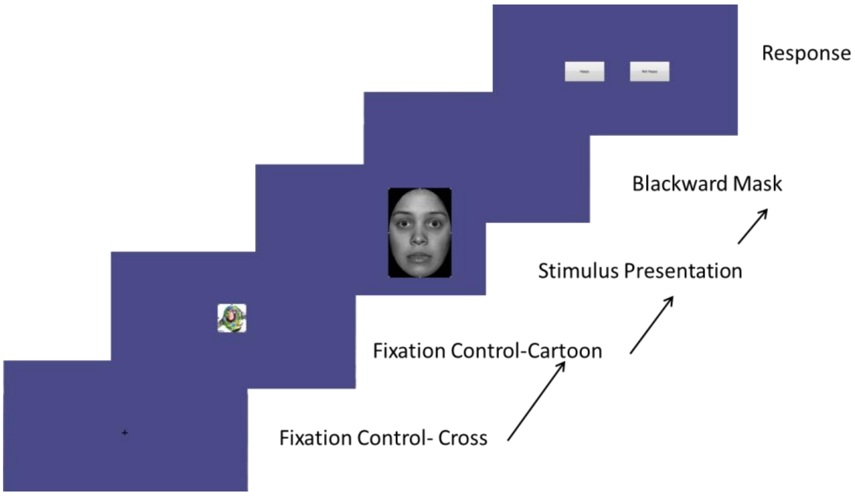

Figure 2. 6. DVF Task: The protocol of events in each trial.

In this thesis only accuracy was measured to be consistent with the CFT methodology, assessing bias only in terms of children’s response accuracy. Children’s responses were a forced choice binary decision and it was possible to acquire accuracy from the number of children’s correct and incorrect responses. In fact the responses were categorised into hits (correctly identify an emotion), misses (incorrectly identify an emotion), correct rejection (correctly identifying a sad emotional expression as non-happy) and a false alarm (identify a sad expression as happy). Children received a score from 1 to 0. They received a score of 1 if they got a hit and correct rejections (clicked the “emotion” button when there was an emotion, or when they clicked the “not emotion” when there was not the target emotion) or 0 if they got a miss, and false alarms (clicked the “not emotional” when there was the emotion, or clicked “emotion” when there was not the target emotion). Signal detection theory measure of accuracy d’ and criterion bias, C’ was then used for analysis (explained in more detail in the methods section of the study 4 in chapter 4).

2.3 Assessing laterality with neurophysiological measures

The chimeric faces test has been validated with participants who have unilateral brain damage (e.g., Kucharska- Pietura and David, 2003), yet, there has been little additional evidence that this is a test of laterality. For instance, is there greater activation in the right hemisphere (RH) than the left hemisphere (LH) and activation levels differ depending on the side of the face that has the emotive information? Given that we are interested in hemispheric activation, rather than specific location of activation, event-related potentials (ERP) can address this question using the electroencephalogram (EEG).

In fact, the great advantage of the ERP methodology is its high temporal resolution. It provides a continuous measure of stimulus processing online even when there is no behavioural response, for example when one passively looks at different emotional stimuli. This excellent temporal resolution of ERPs enables us to study early processing of facial expression within 400ms. Another great advantage of using ERPs especially with children is that it constitutes the most easily adapted of the neuroimaging methods to investigate neural development: it is non-invasive and relatively easy to apply and a relatively low cost technique. As such is considered by researchers a powerful means to complement behavioural studies (Batty & Taylor, 2006; Luck, 2005; Taylor & Pang, 1999). However, the disadvantage of the EEG methodology is its poor spatial localisation of cortical generators of the EEG, or in other words where exactly in the cortex the EEG signal is coming from (which cortical dipoles).However, recent developments in the EEG (e.g. source analysis LORETA- Low Resolution Electromagnetic Tomography) research have enabled researchers to estimate the localisation of source dipoles (Luck, 2005)

In this thesis we are interested in general neural activity on a hemispheric basis in emotion processing. More specifically we are interested in the left versus right hemispheric activation when we see facial expressions. Before the specifics of the EEG research undertaken in this project are discussed, below a review of affective research that looks at the brain regions that process emotive information is provided.

2.3.1 Neural systems for recognising facial expressions

There have been a number of studies that have identified an extensive neural network of facial expression processing in humans. This neural network includes discrete neural regions, namely the occipito-temporal cortices, the orbitofrontal cortex, the amygdala, the basal ganglia and the right parietal cortex (Adolphs, 2002). These regions comprise the emotion circuitry of the brain. Specific brain lesions in the amygdala are associated with impairments in the recognition of fear and sadness. Further, the processing of anger and happiness has been linked to the orbitofrontal cortex, and the processing of disgust has been linked to lesions in the basal ganglia (Murphy, et al., 2003). These aforementioned brain structures are interconnected and interacting and may directly modulate perceptual processing of facial expressions via cortical and subcortical pathways. There may be a subcortical route via the amygdala and the superior colliculus and the pulvinar thalamus, and a cortical route via the frontal and visual neocortex. It is expected that, initially, perceptual processing of a facial expression in the visual cortices would activate structures such as the amygdala and prefrontal cortex. This initial rapid processing is sufficient not only to perceive emotional stimuli (i.e., threatening stimuli) but also perceive them consciously and unconsciously (Adolphs, 2001; Whalen et al., 1998). The response in prefrontal cortex is modulated by the amygdala's activation (as far as vigilance, threat, and ambiguity of stimuli are concerned) and cortical activation suppresses activation of the amygdala. However, the prefrontal cortex–amygdala network feeds back onto visual cortices and contributes to the temporal processing of a fine-grained perceptual representation there (Adolphs, 2001; Hariri et al., 2003). Therefore, there is a top-down influence from the amygdala and the prefrontal cortex that provide information about stimuli emotional information resulting in finer representation of stimuli in visual and association cortices in temporal lobe. In addition to the neuroimaging work with humans, researchers have found support for an amygdala/prefrontal cortex role in emotion recognition in single cell recordings from macaque monkeys. Sugase et al. (1999) recorded the activity of single neurons in the temporal cortex of macaque monkeys while presenting visual stimuli. Single cell (neuron) recordings provide a method of measuring the electro-physiological responses of a single neuron using fine-tipped microelectrodes inserted within (or close to) the cell membrane. The visual stimuli were geometric shapes, as well as monkey and human faces that displayed various expressions of emotion. They found that single neurons conveyed two different aspects of facial information in their firing patterns, at different latencies. Global information, the categorisation of the stimuli as monkey faces, human faces or shapes, was transferred in the earliest part of the processing at about 100ms. In contrast, specific information concerning identity or expression was conveyed later, beginning at about 51ms. after the global information and categorization occcured.

Evidence of early neural activation to facial expressions was found not only in the amygdala but also in orbitofrontal cortex (Ashley et al., 2002; Kawasaki et al., 2001; Krolak-Salmon et al., 2003). In fact, earlier responses to faces have been recorded in humans in orbitofrontal (Kawasaki et al., 2001) and in the lateral prefrontal cortex (Halgren et al., 1994; Marinkovic et al., 2000). The sources of activity from the frontal cortex is consistent with EEG results obtained in the Eimer & Holmes (2002), Holmes et al. (2003) and Pizzagalli et al., (2003) studies, where fearful faces evoked a greater frontal activity around 100 ms when participants were asked to attend to the faces (active viewing of faces), but not when participants were asked to focus on some other element of the task (thereby recording passive viewing of faces).

The point the above review comes to is that when we see facial expressions there is an initial rapid processing necessary to perceive the emotional stimuli globally, and this activity is localised subcortically at amygdala, and cortically at the frontal lobe.

Since Ekman’s investigation (1978) there is a consensus that there are six basic universally recognised emotions and distinct brain regions that contribute to the perception of each specific emotion. Much of the research in laterality with behavioural measures explores laterality for happy processing

(Bourne, 2005) and one negative emotion. For the purpose of this thesis we have chosen to use the happy and sad emotions as they are two of the basic emotions that are recognised and lateralised earliest in life (Herba & Phillips, 2004; Watling & Bourne, 2013, under review). A brief description below will illustrate the current understanding of the neural basis of these two basic emotional expressions as reported by neuroimaging and electrophysiological studies.

2.3.1.1 Neural response to Happiness

Gorno - Tempini et al. (2001) investigated the neural correlates of attending to faces and of passive viewing of faces of happy facial expressions using an fMRI study. The former is otherwise called explicit processing of the faces. The latter, where participants do not attend to the face, is otherwise called implicit processing. Gorno - Tempini et al. (2001) reported activation of bilateral orbitofrontal cortex when participants made judgements of happiness. Phillips et al. (1998) in an fMRI study also reported signal increase in prefrontal cortices during the presentation of happy facial expressions.

2.3.1.2 Neural response to Sadness

Sadness, as opposed to anger, happiness and disgust, is a specifically amygdala mediated emotion (Blair et al., 1999; Calder et al., 1996; Morris et al., 1996; Phillips et al., 1997). In fact, in a PET study Blair et al. (1999) showed that for sad facial expressions of emotion there was an enhanced activity in the left amygdala and in the right medial and inferior temporal gyrus, relative to increasing intensity of sad facial expressions of emotion. This finding has been supported by Blair et al. (2001) who showed in a behavioural study that children with psychopathic tendencies (and reduced empathy) had an impairment of in the processing of sad and fearful facial expressions of emotion and that they required a significantly more intense stimulus to recognise the sad expressions. Since the amygdala is considered critical in the development of empathy and theory of mind (Amaral et al., 1992), Blair's study indicates that there is an association between the amygdala and sad processing impairment.

The neuroimaging studies have excellent spatial resolution, and they have been able to localise activity in the emotion circuitry during processing of emotions. However, there is a wide number of structures activated and this is why neuroimaging studies sometimes report conflicting information as some structures might be sensitive to task manipulations. This makes it important to simplify our understanding of emotion processing at a broader hemispheric level, and, most importantly, when the processing is taking place. In this thesis therefore, the interest is in exploring emotion processing at a hemispheric level using EEG methodology.

The neuroimaging literature above identified two key interacting structures that are specifically responsive to happy and sad emotions. These are the prefrontal cortex and amygdala. Whilst the amygdala is a subcortical deep structure and we cannot record its electrical activity from the cortex, nevertheless, we can measure its activity indirectly as it sends its signals to prefrontal cortex. The latter justifies recording of EEG over frontocentral sites for early facial emotion processing, which has been adopted in the present thesis.

2.3.2 The underlying basis of the EEG signal

The electrical activity of synchronously active large groups of nerve cells in the brain produces currents spreading through the head which also reach the scalp surface. Voltage differences on the scalp can be recorded through electrodes placed on the scalp, as the electroencephalogram (EEG). EEG only records activity generated on the top 0.2-0.3 cm of the cortex's surface (Nunez, 1995). In this small area one can find the cortical layers I - III/IV, where the most common neurons found are the pyramidal cells. These contribute to the origin of the EEG. Pyramidal cells have the shape of pyramids and their apical dendrites are closest to the surface than any other dendrites and they are vertical to the scalp.

There are two main types of electrical activity associated with neurons, action potentials and postsynaptic potentials. Action potentials travel along the axon from the cell body to the axon terminal where neurotransmitters are released. Postsynaptic potentials are the voltages that arise when the neurotransmitters bind to receptors on the membrane of the postsynaptic cell, causing ion channels to open or close and leading to a change in the charge across the cell membrane. Even response potentials (ERPs) reflect postsynaptic potentials. When an excitatory neurotransmitter is released at the apical dendrites of a cortical pyramidal cell, current flow from the extracellular space into the cell will cause a negativity on the outside of the cell in the region of the apical dendrites. In turn, current will flow out of the cell body basal dendrites resulting in a positive charge at the area of the cell body. Together, the negativity at the apical dendrites and the positivity at the cell body create a neuronal dipole with a positive pole on the lower end and a negative pole upwards. Between these two poles electrical current flows from the positive to the negative pole and creates individual electrical fields thousands or millions of which will sum up to produce a dipolar field that can be detected at the scalp. The dipoles of the neurons will only summate to a single dipole (formed by averaging the orientations of the individual dipoles) if the neurons are spatially aligned and synchronously active. This is a feature of the pyramidal cells which are aligned perpendicular to the surface of the cortex (Luck, 2005).

The scalp recorded EEG cannot detect directly the activity of deeper subcortical structures in the brain such as amygdala The activity of these subcortical structures could be detected indirectly via their influence on cortical structures (Vuilleumier, Richardson, Armony, Driver, & Dolan, 2004). There are anatomical connections between amygdala and cortical sensory representation areas in the ventral visual pathway and amygdala directly projects to sensory cortices, providing an effective mechanism to enhance processing of emotions (Leppänen, Andersson, Torkkeli, Knaapila, Kotelnikova, & Serimaa, 2009; Vuilleumier, 2005; Williams, Palmer, Liddell, Song, & Gordon, 2006).

Volume conduction

Another important notion in recording and analysis of ERPs is that of volume conduction. The dipolar field produced by the summated neuronal fields generates a current which is conducted through the brain until it reaches the surface. This is called volume conduction. The voltage recorded at a given electrode site will depend on the position and orientation of the generator dipole and the resistance and shape of different parts of the head such as brain, skull, the scalp and eyeholes. In a conductive medium, because electrical current goes through paths with the least resistance, the ERPs recorded tend to spread out laterally across the brain when there is high resistance of the skull. Therefore, an ERP generated in one part of the brain can be a source of substantial voltages at other distant parts of the scalp and the activity recorded at one site of the brain will be influenced by activity present at further electrodes and does not reflect a direct signal of the activity underneath that specific electrode only. This is one of the biggest shortcomings of the EEG method: its poor spatial resolution. One should be careful, therefore, when interprets ERPs and makes assumptions about localisation of the observed activity (Luck, 2005).

In this thesis we report the activity at different sites but we consider it just indicative when localisation is discussed and in justifying further research.

Recording the EEG signal

One commonly used system of electrode location is the 10-20 system (Jasper, 1958). According to this system each electrode is placed in either 10% or 20% distance from their neighbouring electrodes along two axes: one is the anterior posterior axis, which is the line from the front of the head defined by the nasion, the point between eyes to the back of the head defined by the inion, the small bump at the back of the head. The second axis is from the left to the right is defined by the pre-auricular points. The point at the junction of these two axes is defined as the vertex. In this classification system, a letter is followed by a number or the letter z (e.g. F3, F4 and Fz). The letter indicates at which lobe of the brain the electrode is positioned (frontal, parietal, temporal or occipital), the number defines whether the electrode is to the left (odd numbers) or to the right (even numbers). The front-back midline is defined by the letter z (e.g. Fz). Thus, Fz defines a midline electrode location over the frontal lobe; F3 defines a frontal left site.

Most commonly used electrodes for recording are silver electrode (Ag) and AgCl (Silver Chloride) electrodes. These are considered to be the most stable in their ability to record slow potential changes in the brain (Picton et al., 1995). They are also reversible, which means that the current does not affect the electrolyte composition in the vicinity of the electrode. When an electrode is immersed in an electrolyte a layer of ions is created adjacent to the metal by an exchange of electrons between the metal of the electrode and the electrolyte solution. Additionally, another, second layer of ions is formed beyond the first, which is oppositely charged to the first layer. This double layer acts as capacitor, thus impedes conductivity and the electrode acts as high-pass filter. A reversible electrode eliminates the double-layer effect.

Another factor that needs to be considered is the skin artefacts that can distort and contaminate the ERPs. High impedance can create increased skin potentials (artefacts). The impedance is the resistance to the flow of electrical current; reducing, therefore, the impedance produces cleaner signal. Sweat on a participant’s skin increases the skin impedance. A method to decrease the skin potentials is the careful preparation of the scalp beneath electrodes before recording. The preparation of the scalp involves two steps.

The hair is parted underneath the electrode so it allows a good connection of the electrode to the skin. Second the skin beneath the electrode must be abraded. This is the way to decrease the impedance which should be kept below 10 kΩ. When the preparation of the scalp finishes, a conducting medium connects the electrode to the scalp. Usually this is a cream; for the the eyes a gel is used (Picton et al., 1995).

Reference and Ground

Another important point in EEG research is the concept of a reference. The Voltage measurement represents the potential for current to move from the positive pole to the negative. An ERP waveform reflects the difference between an electrode and a common reference, which is an electrode against which all other electrodes are individually measured. One most common reference used in recording procedure is a linked- ear or linked-mastoid reference where an electrode is placed behind the mastoid bones of the ears and are then linked together (Rugg & Coles, 1995). Finally, a “ground” electrode is used in EEG research which functions to discharge any noise, charge that comes from power lines for instance, or heat and static friction. The ground electrode can be placed anywhere on the nasion-inion axis. In the studies of this thesis, a ground electrode was placed between the Cz and Fz electrodes.

Preparing and cleaning the data

Artefacts and rejection of artefacts

ERP recordings can be contaminated by different artefacts (artefacts are unwanted noise in the signal) which involve eyeblinks, eye movements, and muscle activity. Ways to deal with these artefacts are first to have

participants lean their forehead at a resting bar and rest their chin at a chinrest to reduce head movement during recording; second the experimenter can reduce artefacts occurrence by instructing participants to avoid blinking or moving when the stimulus is presented, and to provide the participants with rest breaks for blinking and moving; third, one can "clean" the raw data by removing artefacts. Artefacts, such as eye movements or blinks can be detected by visual inspection and removed; this is a technique called artefact rejection. One should obtain recordings from ocular electrodes (EOG, electrooculogram) located around the eye (below, above the eye or at the canthi of the eye). This makes it possible to take advantage of the inversion of polarity between eyeblinks and EEG deflections which is very useful when inspecting the single-trial data. Eye movements are saccades, which are shifts in eye position. A saccade elicits a sloped boxcar shape of EOG which can also be detected visually and rejected (Luck, 2005). EOG was recorded in the studies of this thesis horizontally from electrodes placed at the outer canthi of each eye. In this thesis participants were instructed to maintain central fixation at all times during stimulus exposure. Data from trials on which there was lateral movement of the eyes during stimulus exposure were rejected prior to analysis.

Filtering

Filtering optimises the signal by attenuating unwanted frequencies. Several forms of filtering are used in EEG research, the most common being the high-pass (which filters all frequencies higher than a certain cut-off point), low-pass (attenuates all high frequencies lower than a certain cut-off point), band-pass (filters both high and low frequencies, passing only an intermediate range of frequencies) and notch filters (attenuates a small band of frequencies only and passes everything else) filters. The data is highpass filtered on-line, while data is low-pass and band-pass filtered offline after recording and during the pre-processing of the data. Band-pass filters enhance the signal to noise ratio and are mostly applied to filter out electrical noise in the background of the EEG created by mobile phones or electric currents in power cables and sockets. High pass filter at 0.001Hz and Low pass filter at 30Hz were applied in the raw data in order to attenuate frequencies above 30Hz.

Baseline correction

As the main aim of ERPs is to compare the neurophysiological response between different conditions it is important to select an appropriate baseline or zero point to ensure that the compared events did not differ prestimulus.

Usually an interval of 100-200 ms prior to the onset of the stimulus is recommended for baseline. This prestimulus time period is used as baseline because it is not affected by stimulus and it is a period of low activity. In this thesis 100ms pre stimulus was taken for baseline.

Segmentation

After the preparation described so far, the continuous data then is epoched according to the conditions or events. For example in the present thesis where the experiments compared the responses to happy, sad, neutral standard faces the EEG responses were segmented into those epochs which were responses to happy faces, those which were responses to sad faces, and responses to neutral faces The conditions in this thesis for the standard faces are: happy, sad, and neutral; for the chimeric faces the conditions are: happy on the LVF, happy on the RVF, sad on the LVF and finally, sad on the RVF.

Averaging

It is assumed that when one is averaging ERP waveforms across many trials, the ERP waveform remains the same across trials but that the random background noise is reduced. As more trials are averaged the noise gets smaller and smaller, hence more averaging increases the signal to noise ratio. The different epochs obtained through the segmentation for each condition are averaged together for each electrode site and each participant and then all individual averages are averaged to form the grand average. The resulting averaged ERP waveforms consist of a sequence of negative and positive deflections referred to as the peaks or waves or components. These are labelled by their polarity; N refers to negative polarity and P refers to positive polarity. Additionally, a number usually indicates the peaks position in the wave (i.e., N1, P2 or N3). Sometimes the number indicates the typical post-stimulus latency of the peak. For instance, the face specific component is N170 which indicates a negative wave at about 170 ms poststimulus.

The analysis of the electrophysiological data in this thesis will focus on specific ERP deflections shown by the literature to be relevant to facial emotion processing. The description of a peak which this thesis adopted will indicate the peak’s position in the wave. For example the N1 (sometimes called N100 in the literature) is the first negative deflection occurring in the very early window of the EEG (80-120ms). For specific components of significance, names are used, for example the VPP is a positive deflection reversed polarity of N170 with a peak amplitude at approximately 170ms post-stimulus. The following section will provide a brief introduction to these deflections.

2.3.3 ERP components specific to emotion processing

Generally EEG studies differ widely in methodology, including the experimental design, task, stimuli, modality, number and location of recording sites, ERP components evaluation and statistical analysis (Kayser, et al. 1997). However, EEG studies largely seem to agree on earlier and later main ERP components to emotion processing: a positive wave at ~100ms (the P1), a negative wave at ~170ms (the N170) and a negative wave at ~300ms (the N300).

Researchers have debated whether early ERP components demonstrate coarse categorization of visual stimuli (face/non-face) or if there is also a parallel initial categorisation of emotional stimuli (emotional/non-emotional) around 100ms post-stimulus onset. Specifically, two early components have been identified. First, the P1 (typically occurs between 80- 140ms), which is thought to be generated within the primary visual cortex, has been recorded over posterior sites. This P1 becomes polarity reversed at the frontocentral sites and is referred to as the N1. It is like a summed dipole which has the positive side over the visual cortex and its negative side over the frontocentral sites). Second, the N170 (typically occurs between 140- 180 ms), which is generated over occipito – temporal regions becomes polarity reversed at the frontocentral sites and is referred to as the VPP (Again, N170 and VPP are the same processes). Both these components have been identified by research and are suggested to indicate the early encoding of faces. The P1/N1 reflects the global processing of faces, when very early detection of configural changes is occurring (Itier and Taylor, 2002) and is also thought to be when early automatic encoding of emotions occurs; specifically this is when the emotional/non emotional distinction is observed. The N170/VPP is thought to reflect activation of the structural encoding system and involves the component processing of faces as well as a holistic face processor prior to face recognition (Sagiv 2001).

A fair amount of research shows that emotions from faces are processed rapidly and in parallel with other aspects of initial processing of visual stimuli indexed by P1/N1. Halgren et al. (1994, 2000), Pizzagalli et al. (1999, 2002), and Streit et al. (1999) found valence modulated P1 amplitudes from 120ms post stimulus especially from negative expressions, such as fear, anger or sadness. The modulation of the P1 component by fearful faces might reflect an enhanced allocation of attention to threat-related stimuli during initial stages of processing. Additionally, Carretie et al. (2001) showed that the amplitude of the P1 was higher at frontal and central sites in response to arousing unpleasant stimuli than in response to arousing pleasant ones. This enhanced early processing of emotions was also obtained even when the emotional content of faces was not to be explicitly judged by the participants (Batty & Taylor, 2003; Eger et al., 2003; Halgren et al., 2000; Schupp, Ohman et al., 2004) and when emotion of faces were entirely task-irrelevant (Pourtois, et al., 2004).

Greater amplitudes over frontocentral site were shown in a single neuron recording study by Kawasaki et al. (2001). Kawasaki et al., (2001) investigated single-neuron responses to emotional stimuli (scenes and faces) over the prefrontal cortex in an individual (with no brain damage and no intellectual deficits) who was awake. His responses to emotional stimuli were influenced by the emotional content of the stimuli as early as 120-160ms after stimulus onset. However, he reported that the firing rate to aversive stimuli of high arousal (fearful facial expressions) was significantly greater than to happy and neutral expressions. This demonstrates that arousal, rather than just the valence (positive vs. negative) of the emotion, plays a crucial role in the deployment of attention in the early stages of processing facial expressions (Anderson, 2005).

The evidence so far lends additional credence to arguments that the P1 is an index of attention allocation in the area of the extrastriate visual cortex; it differentiates positive and negative but also arousing stimuli which are then allocated different amounts of attention very early in the information processing stream. This is called negativity bias of the P1 (Smith, et al., 2003). Delplanque et al. (2004) further showed that this negativity bias on early attentional processing can be triggered when the arousal dimension is low and participants are engaged in an implicit evaluation task. When, however, Batty and Taylor (2003, 2006), Eimer and Holmes (2002), and Esslen et al. (2004) investigated the time course of all 6 basic emotion processing, they reported a global effect of emotion on P1: early emotion/neutral discriminating ERP starting from around 100ms which was common to six basic emotions with crucial involvement of orbitofrontal cortex.

The face specific N170/VPP component often is discussed as being activated during the initial structural encoding of facial stimuli as faces, just before the identification of a face occurs. It has often been put forth that the N170/VPP is not an emotion activation ERP component. Consistent with the view that this stage of encoding of faces is independent from the encoding of emotions, several studies have found that the N170 component is unaffected by the valence of facial expressions of emotion (Ashley et al., 2004; Eimer & Holmes, 2002; Krolak-Salmon et al., 2001; Pourtois et al., 2004; Pourtois et al., 2005). However, some recent studies have reported some emotional modulation for the amplitude of the N170 (e.g., Batty & Taylor, 2003; Blau et al., 2007; Campanella et al., 2002; Eger et al., 2003; Pizzagalli et al., 2002). For example, the amplitude of the N170 was found to be larger for fearful and surprised faces compared with neutral or happy faces (Ashley et al., 2004; Batty & Taylor, 2003) and was found to be greater for angry than happy faces (Krombholz et al., 2007). Additionally, longer latency of the N170 was also observed for fearful facial expressions (Batty & Taylor, 2003). However, these effects are not always selective for any specific emotional expression, but global, perhaps suggesting attention to general configural changes rather than to emotional significance (Ashley et al., 2004).

It seems that some aspects of emotional processing as depicted by differential activation to negative emotions can occur independently of the face specific activity of the N170 (Itier & Taylor, 2004; Pizzagalli et al., 2002). Findings provide converging evidence that the affective meaning of visual stimuli can be elicited rapidly before the perceptual analysis which differentiates faces from other objects in the posterior visual cortex (Bentin et al.,1996) and the configural analysis within the frontocentral limbic regions (Eimer and Holmes, 2002).

In contrast to ERP responses around 100ms and 170ms, researchers consistently identify a component at approximately 300ms that differs for emotions. Thus, studies have supported the idea that the emotional content of visual stimuli is processed at relatively later stages in emotion processing. For example, variation in the amplitude of the ERP component depending on whether a face displays an emotional expression (e.g., happy, sad) or displays a neutral expression has been reported for the P300 (a positive wave over frontocentral sites which has as its negative counterpart, the N300, over the occipital regions). This is a positive component that occurs around 300ms (after 250ms). Ashley et al. (2004) reported a negative deflection at the latency of 300ms over occipital regions which differentiated disgust from happy, neutral, and fearful expressions. Carretie et al., (1996) also identified a negative wave over parietal sites, the N300, which was sensitive to emotional processes. The stimuli need to be arousing and attractive (of positive valence) to elicit this component. In fact, these later deflections are thought to indicate positive or negative distinction of the emotive information of faces and to indicate sustained selective attention to motivationally relevant information, both of which are important for facial recognition ability (Eimer & Holmes, 2002). Furthermore, Eimer and Holmes (2002) reported ERP modulation that was sensitive to fearful faces beyond 250ms post stimulus over frontocentral sites (the P300). In support of this, Batty and Taylor (2003, 2006) also found differentiation of happy from sad, fear, and disgust facial expressions of emotion in the frontocentral regions.

It seems therefore that first, the main ERPs elicited by emotive information are recorded from occipital, parietal and frontocentral sites during the first 500ms of processing. Second, for every ERP recorded from the occipital and temporal regions there is its counterpart with reverse polarity over the frontocentral sites.

2.3.4 EEG tasks: Explicit and implicit tasks of emotion processing

As discussed previously the neural basis of facial emotion recognition includes a network of cortical and subcortical structures, which are centralised around the amygdala, but that also may involve the orbitofrontal cortex, basal ganglia and right parietal cortex. These tend to be activated when participants are presented with emotional stimuli, and activation varies in the post-stimulus presentation time. Importantly, specific structures are engaged in the processing of specific emotions; for instance, the amygdala is activated by facial expression of fear. The amygdala, is involved in facial emotion recognition through a subcortical route, and a cortical route, via the visual neocortex. Whilst there is evidence that attention to emotional stimuli modulates activity in specific brain areas, more recently researchers have sought to address whether dissociable neural activation underlies explicit and implicit processing of facial expressions of emotion. Several studies have found some overlapping regions for processing of all emotions; they also found dissociation between brain areas involved in the “conscious” (explicit, with a focus on the emotional content of the image) and “automatic” (implicit, with a focus on something other than the emotional content of the image) processing of facial expressions. Critchley et al. (2000) in a fMRI study explored brain activity in an explicit – conscious emotion recognition task (where participants were asked to attend to and judge emotional expressions of happy, angry and neutral faces) and implicit – unconscious emotion task (where participants were asked to attend to and judge the gender of faces). Explicit processing elicited significantly more activity in the temporal cortex, whereas implicit processing evoked significantly greater activity in the amygdala. However, this is not the case for all implicit emotion processing tasks. Whalen et al. (1998) found that the level of amygdala activation was affected by the valence of the facial emotions when they were masked (implicitly processed); there was greater activity of the amygdala to masked fearful facial expressions of emotion while there was decreased activation for happy facial expressions of emotion. Additionally, it has also been found that while there is amygdala activation for both implicit and explicit emotion processing, activation was greater in the explicit task and less in the implicit (Habel et al., 2007). Again, as highlighted earlier, the fMRI findings are inconclusive in terms of how and where emotions are processed.

Research using EEG techniques has found some differentiation in the response latency and activation patterns for explicit and implicit emotion recognition. Knyazev et al. (2009) recorded ERPs in the implicit and explicit processing of angry and happy facial expressions. They found higher early (before 250ms) activity in the right parietal cortex and right insula, whilst explicit processing elicited greater activation later (after 250ms) in the left temporal lobe and in the bilateral prefrontal cortex. Williams et al. (2009) used both explicit and implicit (within a priming protocol) recognition tasks which included the six basic facial expressions to explore recognition accuracy and reaction times measures. Accuracy and reaction time had the opposite pattern for explicit and implicit recognition of emotion. In the explicit condition the responses to happy facial expressions of emotion were more accurate and the responses to fear facial expressions of emotion were the slowest. In the implicit condition exactly the opposite was observed, where the responses to facial expressions of fear were more accurate and the responses to happy facial expressions of emotion were the slowest. This finding reflected the automatic (unconscious) priority for threat-related signals and their slow controlled elaboration when they are consciously attended to. The differences in the specific findings can be attributed to methodological issues. Overall, however, the reported findings are consistent with the suggested distinction between conscious and unconscious mechanisms of emotional processing (Critchley, et al., 2000).

Explicit and implicit tasks of emotion processing have been used in the electrophysiological studies of this thesis and given the previous work in the area, different patterns of activation for different emotions are expected. Study 1 (chapter 3) used an explicit emotion recognition task and an explicit chimeric faces task. In the standard faces explicit task participants were presented with a pair of faces. They were asked to judge which of the two successive faces displayed the target emotion and press 1 with their right-hand index finger if they thought the first image displayed an emotion and press 2 with the right-hand middle finger if they thought the second image displayed an emotion (see Figure 3.1). In the chimeric faces task participants were presented with a pair of chimeric faces. They were asked to judge which of the two successive faces was more emotional and press 1 with their right-hand index finger if they thought the first image was more emotional and to press 2 with the right-hand middle finger if they thought the second chimeric face was more emotional (see Figure 3.2).

Study 2 (chapter 3) used an implicit task (using standard emotional faces and chimeric faces) where attention was not directed towards the emotional faces. Rather, this task was intended to maintain the child’s attention towards stimulus presentation. Each stimulus was succeeded by a circular fixation point which sometimes, randomly, would transform in to a square. Participants were instructed to maintain central fixation at all times, watch the stimuli and when the fixation point was a square rather than a circle press the spacebar on the keyboard.

2.3.5 Preparation, placement of electrodes and recording and analysis in this thesis

The software package Signal 3 (Cambridge Electronic Design Limited, 2001) was used to acquire EEG and facilitate all ERP derivation and analysis. We placed the electrodes according to the 10-20 system described above. The electrodes were AgCl (Silver Chloride) electrodes from three frontal electrode sites (left, right, and midline) and three central electrode sites (left, right, and midline). The ground electrode was placed on the nasion-inion axis between the Fz and Cz. We also recorded an EOG (electrooculogram).

Before beginning the participant was asked to remove any items in their hair, earrings and glasses. If participants had long hair they were provided with hair clips to secure the hair away from their face. A measurement of the participant's head was taken from nasion to inion and between the preauricular points with a measuring tape. The half and the 10% and 20% of these measurements were then calculated and the vertex was found and marked by a grease pencil as the Cz (Central midline). From the Cz, at a distance 20% of the nasion-inion axis was found on the head and marked with a grease pencil, as the Fz (frontal, midline). At 20% distance of the preauricular axis from the Cz left was marked the C3 and right was marked the C4 (central left and right, respectively). At 20% distance of the preauricular axis from the Fz left and right were marked the F3 and F4 (frontal left and right, respectively). Once the points were obtained, the hair was parted so there is no hair beneath the electrode. The skin then at those points was abraded and the electrodes were placed with the help of a conductive cream. The preparation was the same for the placement of the reference electrodes at the mastoid bones, behind the ears, and the ground electrode which was placed between the Fz and Cz along the nasion and inion axis. The area at the canthi of the eye was cleaned with a special lotion and the electrode was placed using a conductive gel for sensitive areas such as the eyes. The EOG in this study was recorded horizontally at the outer canthi of each eye.

The participants were asked to stay as still as possible, to lean their forehead against a bar, place their chin on a chinrest and maintain central fixation during stimulus presentation. Before commencing the recording session, the impedance on each electrode was measured, and this was set at 10kΩ. Those electrodes with impedances exceeding 10kΩ were readjusted so the contact was optimal, and hair was removed from under the electrode obstructing clean contact of the electrode to the scalp. Throughout the recording session, the online EEG was monitored to ensure fair recording from each electrode channel, and if necessary at breaks during the recording session, the electrodes were adjusted to reduce noise on individual channels. During recording the researcher would monitor the EEG signal and attention of participants to the stimuli. At the end of every session the electrodes were washed with a small brush and soapy water and were rinsed and dried.

After data acquisition raw EEG signals were processed of-line to obtain the ERPs: the raw data was filtered, and then were segmented into epochs (for each stimulus type condition) ranging from 100ms prestimulus to 400ms post stimulus. Next, artefacts were identified and removed from the data, by visually inspecting each trial for each participant. Participants who had less than 30 trials per condition were excluded from further analysis.

The next step was to create grand-average waveforms by averaging all the individual-participant waveforms for each condition. The time-windows for specific ERP deflections were specified after each ERP component of interest was placed. The individual peak values (an average across trials for each condition for each participant), not grand-average values, were used for subsequent statistical analysis. The time-windows for the pre-defined deflections were the same for all participants in all epochs across all experimental conditions. There were 3 time-windows for the ERPs of interest suggested by the literature, the N1 in 80-120ms, the VPP between 120-180ms, and the P3 between 180-400ms.

Overall, the differences amongst studies reported above can be attributed to methodology differences such as different tasks (explicit vs. implicit), which could mask specific emotion effects or different stimuli. Krombholz et al. (2007), for instance used schematic faces and the stimuli in Carretie et al. (1996) were not facial expressions but slides of nudes, human remains and landscapes. The fact that most studies report a global effect of emotion shows that emotional processing starts as early as 90ms after stimulus onset and (Batty and Taylor, 2006). Furthermore, the hemispheric specialization for early stages of emotional processing is inconclusive and further research in the area is needed. In summary, the literature suggests three identifiable ERPs within the first 500ms of emotion processing, recorded over posterior sites: the earliest, P1 from 80ms to 120ms, N170 from 120-180 ms and a N300 around 300ms. It has also been suggested by the literature that for every posterior component there is an equivalent reversed polarity counterpart with which coincides in time, over the anterior sites, which reflects the opposite sides of the same dipole generators. Anterior equivalents of P1 , N170 and N300 recorded at occipo-temporal sites have been found to be N1, VPP and P300 which are recorded over frontocentral sites and indicate the same processes as the P1, N170 and N300 (Campanella, et al., 2002; Joyce and Rossion, 2005). The literature also suggested the factors that might influence the processing of specific emotions: the valence, the arousal of emotion and the conscious or unaware processing of the emotion from faces, defined by the task (implicit/explicit). The literature also indicates frontocentral regions to be crucial for emotion processing and a shift towards the right hemisphere towards later stages of processing from P3.

In our physiological investigations, therefore, we recorded ERPs from frontocentral sites only and explored the N1, VPP and P300 peaks in the first 400 ms of facial emotion processing, using an explicit emotion recognition task and implicit emotion task where participants viewed centrally presented emotional faces.

2.4 Validation of the stimuli

In preparation for the studies in this thesis it was important to develop new stimuli. Many papers in the past have used the Ekman faces; however, these have often been critiqued as being dated and for the fact that there is a limited number of identities available (Winston et al., 2002. In contrast to the Ekman stimuli, the National Institute of Mental Health (NIMH) has developed a battery of 672 facial images (NimStim set) posed by 43 professional actors who are from different races or ethnicities, with each individual having 16 images of different facial expressions, including happy, sad, disgusted, fearful, angry, surprised, neutral, and calm. For each expression, separate open- and closed-mouth poses were taken, except for surprise, which was only posed with an open mouth (Tottenham, 2009). Additionally, this set includes three degrees of happy faces (e.g., closed-mouth, open-mouth, and high arousal/exuberant; Tottenham et al., 2009). These were developed for use in studies of face and emotion recognition. Images are available in full colour from http://www.macbrain.org/.

For the studies in this thesis, due to the number of tasks and trials in each study I chose to use the NIMH images; however, these were not validated at the time for verification of the emotional content. Additionally, as I planned to use chimeric faces within this study it was important to create chimeric images and pilot these. The stimuli validation and pilot information is presented below.

2.4.1 Validation of the NimStim facial expressions of emotion

2.4.1.1 Participants

There were 47 participants recruited (31 females), all were Psychology Undergraduate or Postgraduate students. The majority of the participants reported being in 21-30 years age category (95%) with the remaining reporting being in the 40+ age range. 72% were Caucasian, 17% where Chinese, 5% were Indian, and 5% were Asian-other. Two separate groups of participants completed the validation of happy and sad facial expressions of emotion (N = 18) and the validation of angry, fear, and surprise facial expressions of emotion (N = 26).

2.4.1.2 Stimuli

Stimuli were presented to participants as full coloured images from the NimStim Set of Facial Expressions of (NIMH). The images have a width 390 cm and a height of 500cm. All images for each emotion (open and closed mouth) were presented, derived from a total of 43 professional actors. (18 female and 25 male between 21–30 years old). Actors were African- (N =10), Asian- (N =6), European- (N =25), and Latino-American (N=2). Faces included in this validation study were happy, sad, fearful, angry, all with open and closed mouth poses (43 x 2 faces), and surprised (43 faces). Examples of the images are presented in Figure 2.7.

2.4.1.3 Procedure

All the images were presented in blocks of emotions (happy, sad, fear, anger, or surprise) on a 15’ screen Dell laptop using Runtime Revolution 3.0 software. Within each block there were a set of 43 trials. The order of block presentation, as well as the order of trial presentation within each block, was randomized through the program. In each trial, participants were shown a face and asked to make an emotion judgement. Participants would judge if: 1) the emotion was present, 2) the emotion was absent, or 3) the emotion was exaggerated (e.g., “Happy”, “Not Happy”, or “Happy Exaggerated”). They were instructed to make their decision as quickly as possible and click on their choice. If they judged that the emotion was absent or exaggerated the program moved to the next trial. If participants judged that the emotion was present participants were asked to make a judgement as to the extent to which the face was emotive (after clicking ‘happy’ the line would appear with the words ‘happy’, ‘sad’, ‘angry’, etc. to the left of the line and ‘very happy’, very sad’, ‘very angry’, etc. to the right of the line. This emotive judgement was made on a 100 point visual analogue scale that appeared as a sliding bar with no numbers, and where the closer to the right a judgement was made, the more emotive the face was perceived. Once participants made their judgement they click a “Next” button to go to the next trial.

2.4.1.4 Summary of findings

There were 95 images of facial expressions selected as portraying a given emotion by 40% of participants and above. To ensure that the facial expressions chosen from the set were good exemplars of five basic emotions, from the 95 images , we chose those which , on the judgement for how emotive the stimulus was (on 100 point scale, e.g. happy to very happy) had an average emotive judgement greater than 40, for inclusion in later work.

The image representing the relevant emotion, as well as the descriptive statistics for the corresponding emotive judgements are presented in Tables 2.1 and 2.2. This parsing procedure resulted in five categories: happy (n= 15), sad (n=17), angry (n= 21), fear (n= 14), surprise (n=20). Once the images were chosen, neutral expressions of the actors chosen were added to the stimuli used. The inclusion of the neutral expression is important since neutral is often a comparison condition (Tottenham et al., 2009).

Figure 2. 7. Examples of the NimStim affective pictures. From top to bottom showing happy, sad, fearful, angry and surprise posed by females and males (Surprised only open mouth).

Happy Rating					**Sad Rating**				
	N	**Min**	**Max**	**Mean(SD)**		**N**	**Min**	**Max**	**Mean(SD)**
HFO3	13	23	89	59.6 (24)	**SFC3**	10	14	79	59.4 (22)
HFO7	12	31	88	69.2 (16)	**SFO7**	10	1	88	55.5 (26)
HFO9	10	26	98	60.6 (22)	**SFO9**	10	14	79	49.4 (22)
HFO12	12	10	88	53.2 (22)	**SFO12**	10	14	79	49.4 (22)
HFO14	14	36	100	73.1 (19)	**SFO13**	9	38	97	60.5 (23)
HMO23	12	10	100	51 (23)	**SFO14**	9	10	95	49.1 (31)
HFO24	15	9	91	50.9 (28)	**SFC15**	10	21	88	71.8 (20)
HMO25	11	10	85	59.5 (26)	**SFC16**	10	27	95	54.7 (24)
HMO26	10	10	93	60.4 (26)	**SFC23**	9	46	72	57.3 (10)
HMO29	12	25	100	61.6 (25)	**SMC24**	8	30	98	74.2 (21)
HMO35	12	33	89	64.3 (20)	**SMC25**	9	2	61	53 (20)
HMO39	12	31	100	67.9 (21)	**SMO25**	8	27	79	65.7 (17)
HMO40	12	10	100	73.4 (26)	**SMC32**	7	16	99	60.1 (35)
HMO41	11	22	90	58.8 (22)	**SMC39**	7	13	79	53 (29)
HMO43	14	20	100	64.4 (23)	**SMC40**	9	15	89	52.8 (30)
					SMO40	8	54	95	71.5 (13)
					SMO41	9	46	98	76.8 (20)

Table 2. 1. Images of happy and sad rated as happy and sad from the participants. The images were chosen from at least 7 participants and above. From those we chose the images rated as emotional 40% and above.

Angry Rating	**N**	**Min**	**Max**	**Mean (SD)**	**Surprise Rating**	**N**	**Min**	**Max**	**Mean (SD)**	**Fear Rating**	**N**	**Min**	**Max**	**Mean (SD)**
AFC1	21	5	70	59.4 (.18)	**SRPFO3_J**	12	10	87	52.3 (24)	**FFO3**	14	23	100	63,7 (21)
AFO3_J	10	23	100	74.1(24.4)	**SRPFO5_J**	15	21	93	55.8 (24)	**FFO6**	24	10	100	54.3 (27)
AMO8_J	18	13	89	54.8 (21)	**SRPFO6_J**	16	10	94	57 (27)	**FFC7**	18	2	93	45.3 (27)
AMC9_J	19	6	100	50 (30)	**SRPFO7_J**	15	10	100	56.2 (28)	**FFO8**	14	5	100	56 (29)
AMC11_J	20	15	79	36.1 (19)	**SRPFO8_J**	15	10	87	37.9 (22)	**FFO9**	13	26	97	62.8 (20)
AMC14_J	20	3	83	35.1 (24)	**SRPFO9_J**	16	10	100	68.1 (23)	**FFO12**	19	10	92	46.7 (23)
AMC16_J	19	3	81	33.4 (24)	**SRPFO11_J**	11	28	99	57.2 (26)	**FFC17**	23	10	100	38.9 (28)
AMC17_J	24	14	100	49.2 (25)	**SRPFO12_J**	21	1	99	51.2 (20)	**FFO18**	14	13	97	63.2 (27)
AMC18_J	22	1	62	53.8 (19)	**SRPFO14_J**	15	17	94	52 (26)	**FMO20**	14	8	92	33.3 (26)
AMO18_J	21	3	93	60.7 (23)	**SRPFO17_J**	18	4	92	55 (19)	**FMO23**	13	4	100	56 (35)
AMC19_J	21	2	61	55 (18)	**SRPFO18_J**	22	22	86	47.1 (26)	**FMO25**	13	10	88	41.9 (28)
AFO19_J	11	8	100	64.7(30)	**SRPMO21_J**	15	10	93	57.9 (23)	**FMC26**	14	1	83	50 (24)
AMO20_J	15	16	100	62.1(24)	**SRPMO23_J**	19	24	100	41.1 (26)	**FMC29**	21	10	90	44.5 (24)
AMO21_J	20	13	100	46.9 (26)	**SRPMO25_J**	14	5	100	52.7 (26)	**FMC31**	13	10	92	63.1 (27)
AMO23_J	21	4	96	60.3(26)	**SRPMO27_J**	8	18	100	49.2 (23)	**FMC36**	15	10	97	53.8 (27)
SMO24_J	15	26	100	59.2667	**SRPMO28_J**	18	10	90	47.5 (21)	**FMC39**	17	4	95	51.6 (27)
AMO25_J	23	4	98	49.3 (27)	**SRPMO33_J**	14	18	89	54.7 (26)	**FMO40**	10	10	59	34.9 (19)
AMO26_J	22	25	97	60.5 (21)	**SRPMO34_J**	20	1	95	46.5 (23)					
SMO31_J	12	19	98	57.1667	**SRPMO37_J**	14	10	94	50.1 (28)					
AMC32_J	20	14	72	56.7 (18)	**SRPMO38_J**	17	10	90	47.7 (23)					
AMO34_J	19	22	96	67.9 (20)	**SRPMO39_J**	15	22	87	60.1 (20)					
AMO40_J	21	20	100	66.1 (27)										
AMO41_J	19	1	62	38.1 (18)										
AMO42_J	18	18	96	57.1 (22)										

Table 2. 2. Images of angry, surprise, and fear rated as angry, surprise, and fear from the participants. The images were chosen from at least 10 participants and above. From those we chose the images rated as emotional 40% and above.

2.4.2 Design and pilot of a NimStim set of chimeric faces

2.4.2.1 Designing the chimeric faces

Using the validated happy, sad, and angry images selected from the NimStim set of faces, a set of chimeric face stimuli were created. All full face images were first converted to black and white. All faces were then vertically split (using the nose as a reference for central divide) with Adobe Photoshop CS4. The right side of the emotive image / left side of the poser's face (the left side of the face has been found to be more emotive; Mandal & Ambady, 2004) was used in the creation of the chimeras. The emotion hemifaces then were attached to neutral hemifaces so that half of the face showed an emotional expression (happy, sad, or angry), and the other half shows a neutral expression from the same poser. A black oval mask was then placed over the face, so just the emotional information was showing. These were the original chimeric faces. A mirror image of each original face was then created by 'flipping' on the horizontal the image in Adobe Photoshop CS4, to create a set of images where one image had the emotion on the left side and one had an identical image with the emotion on the right side (mirror image) from the viewer's point. In total 15 happy chimeras, 17 sad, and 21 angry chimeras were created. Examples of the chimeras created are shown below in figure 2.8.

Figure 2. 8. Examples of happy, sad and angry chimeras created. The emotion is shown in the LVF in the top chimeras and in the RVF in the bottom chimeras.

2.4.2.2 Piloting the chimeric stimuli

This small study was a behavioural test of lateralisation, the chimeric faces test, which aimed to measure the strength of lateralisation for facial expression recognition using NIMH's faces chimeras that were developed. Before beginning the EEG work it was important to explore if the happy and sad chimeras produce a similar bias to that seen in other chimeric tests (i.e., show a similar bias). The CFT test was designed, therefore, to replicate work by Bourne (2000, 2005, 2010) and Workman et al. (2000) with adults, who have found that laterality quotients for emotion processing range from 0.25 to 0.17.

2.4.2.3 Participants

Thirty three right handed participants with age range from 16 to 40+ years, were recruited (22 females). All were Psychology Graduate and Postgraduate students. The majority of the participants reported being in the 21-30 age category (39.4%), in the 16-20 age category being the 27.3%, in the 30 to 34 age range being the 15.2%, in the 35-39 age range being the 12.1% with the remaining 6.1% reporting being in the 40+ age range. 51.5.9% were White British, 30.3% were White Other, 6.1% Chinese, 6.1% Asian Other, 3% Indian and 3% White Irish.

2.4.2.4 Stimuli

A total of 24 pairs of chimeric faces (a chimera and its mirror image) were presented, 12 pairs for each of happy and sad emotions. The pairs were presented in two blocks of happy and sad. All the faces were presented in greyscale and in a black background, showing a frontal image of the face. All the images were presented on a 15” screen Dell laptop computer using Runtime Revolution 3.0 software. The program randomised the order of presentation of the blocks. It also randomised trials within blocks. The participants were presented with the pairs of chimeric faces, one above the other. Each face subtended approximately 6.5° horizontally and 9° vertically. The distance between the two faces was 0.001°. Each pair was presented twice in the block. One pair would have the top face showing the emotion on the LVF and the bottom face would show the emotion on the RVF. The second pair had the same faces in the reverse place: the top would show the emotion on the RVF and the bottom on the LVF. Placement of the two faces (top or bottom) and order of presentation was counterbalanced and was randomised between participants.

2.4.2.5 Procedure

Participants were instructed to concentrate on the faces and decide which they thought looked happier or sadder and click on their choice. When each pair was presented at the centre of the screen the cursor was positioned in the middle between the two faces. In that way any upward movement would enable participants to click on the top face and any downward movement would enable them to click on the bottom face. The pictures stayed on the screen until the participants responded. From the responses a laterality quotient (CFT-LQ) was calculated (see section 2.2.2) ranging from -1 to +1 (-1: always choose the emotion in the right visual field indicating left hemisphere advantage, +1: always choose the emotion in the left visual field, indication of right hemisphere dominance).

2.4.2.6 Analyses

The mean laterality quotient for both emotions combined was .16 (SD = .38) and this was significantly different from zero, *t* (32) = 2.55, *p* = .016, indicating a left visual field (RH) bias. For happy chimeras the mean laterality quotient was .20 (SD = .52) and for sad .14 (SD = .36). One-sample t tests compared the laterality quotients for happy and sad images to a score of zero (indicating no laterality bias); laterality quotients were significantly different from zero for happy chimeras, t (32) = 2.23, *p* =. 033, and sad chimeras, t (32) = 2.16, *p*=.038, indicating a significant right hemisphere bias for both emotions.

2.4.2.7 Summary

The finding of this pilot study, showed that with the new stimuli adults have a left visual field bias (RH advantage) for both happy and sad emotions in the chimeric faces task. It replicated, therefore, previous studies which use alternative CFT stimuli to assess laterality (e.g., Bourne, 2000, 2005, 2010; Levy et. al., 1983; Workman, 2000). These stimuli were therefore used in subsequent work in this thesis.

Chapter 3: Researching facial emotion processing and laterality: Electrophysiological investigations

The review on the facial emotion recognition (Chapter 1) showed that an understanding of emotions from facial expressions is an ability that develops between 4 and 11 years old and different emotions are recognised at different stages of development. For example, happiness is recognised accurately at a level similar to adults at 4 years of age, sadness by 5 to 6 years of age, fear at 7 years, anger at 9 years and disgust at 11 years (Durand et al., 2007; Herba & Phillips, 2004; Reichenbach & Masters, 1983; Vicari et al., 2000; Widen & Russell, 2003). Much of the early research on emotional development explained the development of emotion recognition in terms of social factors such as individual differences in children's social experiences and interactions with family and peers (Camras et al., 1990; Gordon, 1989). Moreover, recent research has focused on the maturation of the brain processes and structures in order to explain the development of emotion understanding. One line of investigation has focused on the development of hemispheric lateralisation for emotion processing.However, there is no direct evidence linking behaviour tests of lateralisation to left and right neural activation.

Lateralisation of emotion processing in the adult brain has been mainly the focus of behavioural neuropsychological studies. In addition to using tachistoscopically presented stimuli as a measure of brain asymmetry, the chimeric faces test (CFT) has been widely used as a measure of lateralisation of emotion processing (Levy et al., 1983). As discussed in chapter 2, the CFT uses chimeric faces which are faces created from an emotional hemi face and neutral hemi face. The chimeric faces are presented centrally either in pairs with one above the other (e.g., Bourne, 2000; Levine & Levy, 1986; Workman et al., 2000, 2006) or presented centrally one chimeric face at a time (e.g., Bourne & Gray, 2011). Kucharska-Pietura and David (2003) have validated the CFT with individuals who had left, right, or no hemisphere damage. They found that both non-clinical participants and patients with unilateral left hemisphere lesions showed a left visual field bias and judged chimeras with the emotion on their left hemifield as more emotive than chimeras with the emotion on their right hemifield, while patients with unilateral right hemisphere lesions showed significantly reduced left visual field biases; thereby demonstrating a right hemisphere dominance for emotion processing. This reduced left visual field bias in adults has been also replicated and reported by Bava et al. (2005) with children who have unilateral focal brain lesions. Numerous studies with non-clinical populations used the CFT to explore the hemispheric biases in the perception of facial expressions of emotions (Bourne, 2000, 2008; Lane et al., 1995; Levy et al. 1983; Luh et al. 1991) and reported a general trend in the population of a left visual field bias (RH advantage) in the processing of all emotions. However, the neural markers of the observed lateralisation have largely been unexplored, and are therefore unknown; most importantly, there has been no research exploring activation patterns for laterality when viewing and making decisions about emotional chimeric face stimuli. This chapter will set out to explore neural activity, on a hemispheric basis, in emotion processing. The primary aim of the studies presented in this chapter is to validate the CFT as a test of laterality using EEG technique where we will explore ERPs when chimeric stimuli are presented.

Previous EEG research has identified three key responses which reflect processing of facial expressions. As discussed in section 2.3.3, there is an early negative wave about 80-120ms post-stimulus (N1), a positive wave at about 130-200ms (VPP) and a later positive wave from 200-400ms (P300), over frontocentral sites. In fact, while ERP studies differ in the type of task and stimuli used, as well as the experimental design, number and location of recording sites (Kayser et al., 1997), there is consensus across studies on the basic characteristic electrical response patterns in the brain to viewing emotional facial expressions. Several studies have supported a model of automatic, rapid processing of emotional expressions that are indicated by an early (from 90-120ms) positive wave (P1) recorded at parietal sites which reverses its polarity at frontocentral sites becoming a negative wave (N1). The P1/N1 is when the global processing of faces takes place, including the detection of configural changes in faces (Itier & Taylor, 2002); this is where the emotional/non emotional distinction is observed. Following the P1/N1 there is a negative wave at about 170ms (N170) which is a face specific ERP and has its positive counterpart over central sites (VPP). The N170/VPP has been suggested to be activator of a structural encoding system and involves the processing of the components of faces as well as a holistic face processor prior to face recognition (Sagiv, 2001). We look at this face specific ERP because several studies (see chapter 2) reported modulation from emotional information of faces. At the later latency (200-400ms) there tends to be a positive wave over the frontocentral sites (P300). This late positive wave has been identified as reflecting the process of discrimination and recognition of emotive visual stimuli (Carretie et al., 1996). The N1/P1 and P300/N300 potentials identified are thought to reflect two stages of emotional processing. An early one reflected by the N1 where the emotional/non-emotional distinction of neutral from emotional stimuli as a categorical decision is performed and a later stage (P300) where the positive/negative distinction is continually processed, the processing of emotional stimuli is completed and memory-updating occurs. The face specific N170/VPP modulations by emotional faces are of interest because they reflect the independence of face versus facial emotion processing (Bruce &Young, (1986). ERP responses to chimeric face presentation will be explored in the two studies presented in this chapter at these three identified points. Additionally, as most previous work has explored facial expressions processing with full faces in both studies there is a full face viewing task.

A second key aim of this chapter is to assess the development of laterality using ERPs for facial emotion recognition. As explained in chapter 2, the ERP methodology amongst other neuroimaging methodologies, such as fMRI and PET, has the advantage that it enables the assessment of neural processing of affective stimuli in milliseconds (Batty & Taylor, 2003; Olofsson, Nordin, Sequeira, & Polish, 2008). Furthermore, the ERP methodology has been described by Batty and Taylor (2006) as the most easily adapted of the neuroimaging methods and therefore the most appropriate (Taylor & Pang, 1999) to investigate neural development, cerebral lateralisation of emotion processing in young children which can be used to complement behavioural studies (Taylor & Pang, 1999). As such, exploring ERP activation may explain some of the variance observed in the developmental trends for children’s facial expression recognition.

In summary, Study 1 is designed to explore the left versus right hemispheric activation when viewing both chimeric faces and full faces that display facial expressions of emotion at both frontal and central sites. Study 2 is designed to explore developmental differences in left and right hemispheric activation between 5 and 13 years, with an adult comparison group.

3.1 Study 1: Electrophysiological evidence of hemispheric lateralisation in adults

Many EEG studies to date (e.g., Batty & Taylor, 2003; Kayser, Tenke, Nordby, Hammerborg, Hugdahl, & Erdmann, 1997; Kestenbaum, 1992; Laurian, Bader, Lanares, & Oros, 1991; Munte et al., 1998; Vandeerploeg, Brown, & Marsh, 1987) that have explored emotion recognition have placed an emphasis on the timing of when emotions are being processed in the brain and have not examined the extent to which lateralisation of emotional processing may exist. This study was designed to investigate the patterns of electrophysiological responses of early emotional processing at frontocentral sites in adults and to explore if adults' activation patterns show hemispheric lateralisation for facial emotion processing. This study aims to validate the chimeric faces task as a test of laterality using electrophysiological measures (ERPs).

As highlighted there is evidence that the N1, VPP, and P300 indicate different levels of emotion recognition. However, there has also been evidence that these components are not modulated by different emotions (Balconi & Lucchiari, 2005; Eimer et al., 2003; Holmes et al., 2005; Munte et al., 1998). Studies support the idea that early in the processing of faces an initial structural encoding occurs which provides descriptive information for subsequent expression and identity recognition of faces (Ashley et al., 2004; Eimer & Holmes, 2002), which is reflected in later ERPs such as the P300. Given that the primary aim of this study is to examine if there is differential hemispheric activation when viewing chimeric faces with the emotion presented on the left versus the right, and that there is no previous work exploring electrophysiological responses to chimeric faces, a full face viewing task was also included. With chimeric faces it would be expected that there would be differential hemispheric activation dependent on the hemifield the emotion was presented in. However, it is also of interest to discover when viewing emotive full faces whether there is greater activation in the left or the right hemisphere.

Given that behavioural studies have found that lateralisation for emotion processing is present in adults, this study explores ERP responses of adults. While researchers have found evidence of differential N1 and VPP activation for emotive and neutral faces, it was expected that particular laterality effects would emerge in the late wave components. Based on the behavioural evidence of lateralisation for emotion processing and physiological evidence of lateralisation of the main components identified (P1/N1, N170/VPP and N300/P300) at different latencies of emotion processing (Batty & Taylor, 2003; Kayser, et. al. 1997; Kestenbaum, 1992; Laurian, et. al., 1991; Munte, et. al., 1998; Vandeerploeg et al., 1987) it was expected that there would be a RH advantage at some point within the first 400ms of processing. Additionally, consistent with this point, it was expected that the ERP responses to happy and sad chimera would reflect the crossed nature of the visual system whereby chimeras with the emotion on the left visual field would elicit greater amplitude over the RH and chimera with the emotion on the right visual field would elicit greater amplitude over the LH.

3.1.1 Method

Participants

Thirty-five undergraduates (9 males, 26 females), M_{age}(SD) = 26.9 (7.7) years, age range 17 to 49 years, were recruited through the Research Participation Scheme in the Department of Psychology, Royal Holloway, University of London, and were given course credit for their participation. Participants completed the handedness questionnaire by Dorthe et al. (1995). As explained in section 2.2.1, the questionnaire was comprised of 17 items, each measured on a seven-point Likert scale form -3 (always with the left hand) to +3 (always with the right hand). The scores were summed to obtain a handedness score ranging from -51 (strongly left handed) to +51 (strongly right handed). Thirty two participants self-reported being right handed. These had a mean score of 30.9, (SD = 5.7; range from 21 to 51). Data from participants who reported being left handed were not included in the analysis. Participants were fully informed as to the nature of the study and provided with written informed consent. All participants reported having normal or correct to normal eyesight, were not on any medication that would influence performance, and did not have any brain damage.

This study was approved by the Ethics Committee of the Department of Psychology of Royal Holloway, University of London.

Materials

The stimuli were black and white photographs of NIMH (National Institute of Mental Health) pictures of individuals displaying facial expressions of happy, sad, and neutral. The study was designed to use as many identities possible to make sure any effects were from the facial expression and not the face. Fifteen happy, 15 sad faces and the neutral ones of the same identity as the emotional faces were chosen from the validated faces (see Section 2.4.1). From these, 9 were faces of a male and 6 faces of a female. These are subsequently referred to as standard faces.

Emotion recognition task stimuli. This task used each of the 15 standard happy faces, 15 sad faces, and 15 neutral faces.

Chimeric Faces Task stimuli. From these validated standard faces, the chimeric faces that were developed for sad and happy emotional expressions were used (see Section 2.4.2), where one side of the face displayed an emotion (either happy or sad) and the other side was neutral. In total there were 60 chimeras (15 happy with the emotion on the left side of the face, 15 sad with the emotion on the left side of the face and their mirror images where the emotion was on the right side of the face).

Procedure

Participants were all invited to the EEG lab within the Psychology Department. Electrodes were placed on their head frontocentrally according to the 10-20 system, as outlined in section 2.3.2: three frontally, over left, right hemispheres and midline, the F3, F4 and Fz, respectively; three central electrodes over left, right hemispheres and midline, respectively. For the EOG two electrodes were placed at the outer canthi of each eye. For reference two electrodes were placed behind the mastoid bone of each ear and one ground electrode was placed on the nasion-inion axis between the Fz and Cz electrodes. Each participant was seated in a dark room and a 17”computer screen was placed at a viewing distance of 70cm. Their head was comfortably positioned with their chin in a chin rest. They were instructed to sit still and maintain central fixation during stimulus presentation. There was a curtain that was drawn across the room to separate the participant and the experimenter to reduce distraction.

The participants performed two tasks whilst having their electroencephalogram (EEG) recorded: I) an emotion recognition task and ii) a chimeric faces task (CFT). These tasks were randomised for each participant as to which was first and second.

Within each task, each block contained 80 trials with the same emotion being displayed (happy or sad). Each trial began with a fixation cross that was presented for 1000ms to focus attention. When the fixation cross disappeared a face would appear for 500ms, followed by a second fixation cross for 1000ms, and then a second face for 500ms. The stimuli within each trial were presented in a randomised order, and the trials were randomised within each block. Following the presentation of the second of the face participants made a judgement about the emotive nature of the two faces by always pressing the 1 with their right-hand index finger to indicate the first face was more emotive or the 2 with the right-hand middle finger to indicate that the second face was more emotive.

Emotion recognition task (standard faces). This task had two blocks, one with the happy emotion and one with the sad emotion. The order of presentation for the emotion block was randomised between participants (i.e., with some receiving the happy block first and the sad block second, and with some receiving the sad block first and the happy block second). Within each block there were 80 trials. In the trials for this task, one of the faces presented was the emotional face and the other of the two faces was a neutral face. The order of the two blocks of trials was randomised. The 80 trials were block randomised. Of the 80 trials, half of the trials had the neutral face presented first and the emotive face presented second. Within each block the order of the trials was randomised for each participant. Participants were asked to judge which of the two successive faces displayed the emotion (see Figure 3.1). They were instructed to press 1 with their right-hand index finger if they thought the first image displayed an emotion and to press 2 with the right-hand middle finger if they thought the second image displayed an emotion.

Chimeric faces task. This task had two blocks, one with the happy chimera and one with the sad chimera. The order of presentation for the emotion block was randomised between participants (i.e., with some receiving the happy block first and the sad block second, and with some receiving the sad block first and the happy block second). Within each block there were 80 trials. In the trials for this task, one of the chimeric faces had the emotion in the left visual field (LVF, original) followed by its mirror image with the emotion in the right visual field (RVF). Of the 80 trials, half of the trials had the RVF chimeric face presented first and the LVF chimeric face presented second, and half of the trials had the opposite with the LVF chimeric face presented first and the RVF chimeric face presented second. The order of the trials was randomised for each participant. Participants were instructed to press 1 with their right index finger if they thought that the first chimera was more emotive (happier or sadder) than the second and press 2 with the right middle finger if they thought the second chimera was more emotive (happier or sadder; see Figure 3.2).

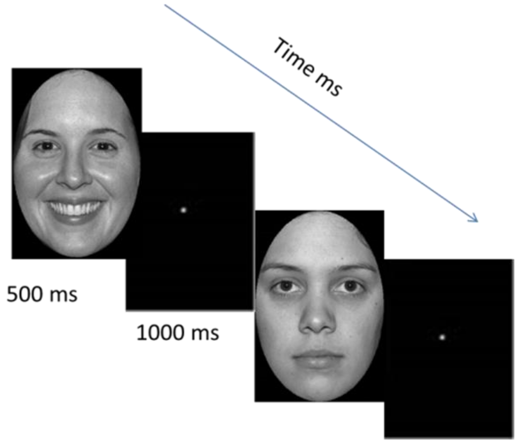

Figure 3.1. Schematic of Emotion Recognition Task (standard faces).

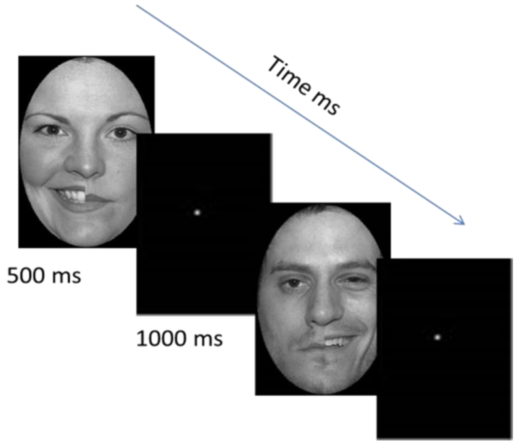

Figure 3.2. Schematic of Chimeric Faces Task.

The above tasks (the emotion recognition task and the chimeric faces task) were explicit emotion tasks as the attention is directed to the emotion of the faces (discussed in section 2.3.4)

ERP Recording and Analysis

As highlighted in section 2.3.2, and the procedure section above, ERPs were recorded with Ag-AgCl electrodes and linked-mastoid reference from Fz, F3, F4, Cz, C3, C4 according to the 10-20 system), with a sampling rate of 1000 Hz, and a band-pass filter of 0.01 Hz. Horizontal EOG was recorded bipolarly from the outer canthi of both eyes. The impedance for all electrodes was kept below 10 KΩ.

All recordings were analysed and processed off-line after data acquisition. Trials with artefacts (e.g., mainly eyeblinks) were excluded from the analysis after visual inspection of the raw data. EEG and EOG were epoched off-line into 500-ms periods starting 100ms pre-stimulus and ending 400ms post-stimulus onset. For a participant's waveform to be included in the analyses there was a minimum of 30 individual waveforms. Of the 32 participants one participant had fewer than 30 individual waveforms (due to artefacts and eyeblinks) and this participants data was therefore excluded from analysis. For each task, and within each emotion block (happy or sad), analyses were conducted on the ERP responses to the first face of the pairs only. Looking only at ERP responses to the first face allowed control of knowledge about emotional content (i.e., the first facial image was always predictive of the emotional content of the second face) and would mean that any issues of expectancy did not confound analyses. Separate averages of amplitudes were computed for all conditions within task and for each emotion block. These were calculated for each participant and for the six electrodes sites (F3, Fz, F4, C3, Cz, C4), culminating in the calculation of grand averages for all participants in each condition.

The grand waveform averages from the standard face trials in the emotion recognition task were analysed using 3 x 3 x 2 repeated measures ANOVAs including the variables expression (happy, sad, neutral), hemisphere (left, middle line, right), and electrode site (frontal, central). Therefore, for the standard face trials all three levels of the laterality electrode factor were included in the analysis (left: F3, C3/midline: Fz, Cz/ right: F4, C3). Any significant interactions were followed-up using either post-hoc tests or lower level ANOVAs to evaluate the reason for this interaction.

The grand waveform averages from the chimeric faces trials in the chimeric faces task were analysed using 2 x 2 x 2 x 2 x 2 mixed measures ANOVAs, with the repeated variables being emotion (happy sad), hemisphere (left, right), visual field presentation of emotion (LVF, RVF), and electrode site (frontal, central), and with group as the between subjects variable (explained below). Therefore, for the chimeric faces task a two level factor for laterality was used (right and left hemisphere). Amplitudes over both hemispheres were measured and analysed on each trial. This was because in the chimeric faces task the main focus was the interaction of each the visual field (VF) with their contralateral hemisphere. Type 1 errors associated with inhomogeneity of variance were controlled by using the Greenhouse-Geisser epsilon where appropriate (Jennings and Wood, 1980). Any significant interactions were followed-up using either post-hoc tests or lower level ANOVAs to evaluate the reason for this interaction.

In addition to the analyses for the standard faces, for the chimeric faces we also added a factor of group. We formed this factor on the basis of the behavioural data. From the participants’ judgements of which face was more emotive (the first or the second in a trial) we calculated a mean laterality quotient for all chimeras and a laterality quotient (see section 2.2.2) for the sad and happy chimeras, separately. The laterality quotient ranged from -1, which meant that participants always chose the chimera with the emotional expression in the RVF thereby indicating a left hemisphere bias for the task, to +1, which meant that participants always chose the chimeras with the emotion in the LVF thereby indicating a right hemisphere bias for the task. We performed a median split on the data, with the first group comprising the participants who showed the most rightward bias (LH) in their responses, and the second group comprising those subjects who showed the most leftward bias (RH) in their responses (Table 3.1). We will refer to these as LH laterality group and RH laterality group, respectively.

GROUP	N	Minimum	Maximum	Mean(SD)
LH laterality group	15	-.92	.40	-.09 (.37)
RH laterality group	16	.41	1.00	.70 (.18)

Table 3. 1. Laterality Groups: Mean (SD) of total Laterality Quotient.

It was expected that the two groups of adults (the RH group with left visual field advantage and the LH group with the right visual field advantage) would have different amplitudes across the two hemispheres but in opposite directions: The LH laterality group would show greater amplitudes over the left hemisphere and the RH laterality group would show greater amplitudes over the right hemisphere.

For both tasks and all of ANOVAs, we performed the analysis on three separate time (temporal) windows: 80-120 ms, 120-180 ms and 180-400 ms. The general cortical response included a prominent, early negative peak between 80- 120ms, a subsequent positive peak from 130-180ms and later positivity from 180-400ms. Whilst it might not be helpful to assign labels to these windows, these are analogous to and will be referred to through the analyses as the N1, VPP and P3 components (e.g., Joyce & Rossion, 2005; Luck, 2005; Picton, 1995; see also Chapter 2 for more information on these components). In all cases we only report main effects or interactions that involve non-electrode factors (e.g., emotion, visual field, and group). Only significant effects and interactions are reported.

3.1.2 Results.

Standard faces

Table 3.2 shows the mean and standard error of the amplitudes in microvolts within the three temporal windows, for each of the standard face conditions. We submitted the mean voltages for each of these windows to a set of repeated measures ANOVA (as described in the methods section, 3.1.1

Standard faces

		N1			VPP			P300		
	Emotion	Happy	Sad	Neu	Happy	Sad	Neu	Happy	Sad	Neu
Frontal	F3	-.103 (.033)	-.067 (.027)	-.076 (.024)	.266 (.043)	.146 (.003)	.229 (.044)	.132 (.045)	.207 (.058)	.117 (.041)
	Fz	-.232 (.037)	-.173 (.035)	-.196 (.031)	.416 (.053)	.168 (.038)	.378 (.043)	.106 (.055)	.174 (.067)	.052 (.005)
	F4	-.192 (.033)	-.134 (.032)	-.150 (.029)	.351 (.042)	.158 (.033)	.331 (.035)	.128 (.047)	.182 (.054)	.094 (.043)
Central	C3	-.163 (.041)	-.140 (.038)	-.162 (.031)	.383 (.057)	.204 (.041)	.333 (.049)	.220 (.057)	.255 (.061)	.139 (.050)
	Cz	-.295 (.046)	-.261 (.045)	-.262 (.035)	.466(.054)	.182 (.035)	.421 (.050)	.126 (.054)	.153 (.063)	.039 (.056)
	C4	-.184 (.034)	-.140 (.032)	-.155 (.027)	.381 (.044)	.205 (.033)	.352 (.041)	.206 (.049)	.227 (.054)	.137 (.047)

Table 3. 2. Means and standard errors of the amplitudes for N1, VPP and P300 for happy, sad and neutral standard faces

Standard face trials:

Early temporal window (80-120ms), N1

In the time window most closely resembling the N1 effect, there was a significant main effect of emotion, *F* (2, 60) = 4.080, *p* =.022, η^2= .120. Pairwise comparisons showed that happy faces evoked significantly greater amplitudes than sad faces (M (SE) = -.195 (.031) and -.152 (.029), respectively, p = .041. However, there was no significant difference between happy and neutral faces (M (SE) = -.195 (.031) and -.167 (.025), respectively, p = .296) and neither between sad and neutral faces (M (SE) = -.152 (.029) and -.167 (.025), respectively, p = .745. The main effect of hemisphere was significant, *F* (2, 60) = 29.450, *p* <. 001, η^2 = .495 whereby the amplitudes over the midline (Fz and Cz) were significantly greater than over the left hemisphere (F3 and C3), (M (SE) = -.236 (.034) and -.118(.023), respectively, p <. 001) and the amplitudes over the right hemisphere were significantly greater than over the left hemisphere (M (SE) = -.159 (.028) and -.118 (.023), p = .044.

Middle window (130-180ms), VPP:

In the time window most closely resembling the VPP effect, there was a significant main effect of emotion, *F* (1.41, 42.36) = 25.605, *p* <. 001, η^2 = .460 with amplitudes being significantly different between happy and sad faces (M (SE) = .371 (.041) versus .177(.029), respectively, p < .001) and between neutral and sad faces (M (SE) = .341 (.039) versus .177 (.029), respectively, p < .001). However there was no significant difference between the responses to happy and neutral faces (M (SE) = .371 (.041) versus .341(.039), respectively, p = .338). The main effect of hemisphere was significant, *F* (2, 60) = 8.394, *p* =. 001, η^2 = .219, showing the amplitudes over the midline electrodes to evoke significantly greater amplitude than over the left hemisphere, p < .001.

Importantly, there was a significant interaction between emotion, hemisphere and electrode location, *F* (2.32, 69.75) = 3.624, *p* = .026, η^2 = .108. This interaction was broken down to explore if an emotion by hemisphere interaction existed at both electrode locations. Simple effect analyses demonstrated that it was only at the midline central electrode location that there were significant differences in activation to the emotional faces (Cz), *F* (1.46, 43.71) = 27.723, *p* < 0.001, η^2 = .480. Pairwise comparisons showed that there was a significant difference between happy and sad (M (SE) = .466 (.054) versus .182 (.035), respectively, p < .001) and by a significant difference between neutral and sad (M (SE) = .421 (.050) versus .182 (.035), respectively, p <. 001). The difference between happy and neutral was not significant, p = .293 (Table 3.2).

Late window (180-400ms), P300:

In the time window most closely resembling the P300 effect, it was observed a significant effect of emotion, *F* (1.68,50.49)=10.411 *p* <.001, η^2 =.258, with amplitudes being significantly different between neutral and sad faces (M(SE) = .096 (.044) versus .199 (.055), respectively, p < .001) and between neutral and happy faces (M(SE) = .096 (.044) versus .153 (.044), respectively, p = .019).The difference between happy and sad faces was not significant, p = .292.

There was also a significant main effect of hemisphere, *F* (2, 60) = 5.960, *p* = .004, η2 = .165, with amplitudes being significantly different between left hemisphere and midline sites (F3, C3/Fz, Cz) ((M (SE) = .178 (.044) versus .108(.054), respectively, p = .002). The difference between left hemisphere and right hemisphere was not significant and neither was the difference between the right hemisphere and midline, p values >.097.

Summary of the standard face electrophysiology results:

Early in the epochs, the amplitudes that we recorded were sensitive to the emotional content of the standard faces presented. This was primarily driven by a large difference between the responses to happy and sad faces. Midway through the epochs (130-180 ms) the emotional content of the standard faces had its greatest effect on amplitudes over the midline central electrode (Cz). This was driven by a significant difference between the responses to sad and the other two expressions (happy and neutral). In the final period of the epoch (180-400 ms) with the standard faces we primarily observed a generic target versus non-target effect. That is, the amplitudes distinguished both happy and sad faces from the neutral non-targets, but they did not distinguish the different emotions.

Chimeric faces trials:

Table 3.3 shows the mean and standard error of the amplitudes within the three temporal windows, for each of the chimeric face conditions. We submitted the mean voltages for each of these windows to a set of repeated measures ANOVA (as described in the methods section).

Chimeric Faces Means (SE)

		N1				VPP				P300			
		Happy LVF	Happy RVF	Sad LVF	Sad RVF	Happy LVF	Happy RVF	Sad LVF	Sad RVF	Happy LVF	Happy RVF	Sad LVF	Sad RVF
Frontal	F3	-.037	-.071	-.042	-.044	186	103	. -001	.126	.290	.216	268	270
		(.032)	(.032)	(.03)	(.026)	(.038)	(.040)	(.002)	(.030)	(.057)	(.051)	(.055)	(.053)
	Fz												
	F4	-.095	-.098	-.137	-.135	154	.119	.092	.105	246	.256	218	.238
		(.037)	(.041)	(.036)	(.042)	(.042)	(.044)	(.045)	(.035)	(.058)	(.052)	(.053)	(.052)
Central	C3	-.132	-.126	-.135	-.146	.201	.129	.139	.159	.267	.235	271	.267
		(.044)	(.05)	(.037)	(.046)	(.038)	(.049)	(.041)	(.039)	(.045)	(.046)	(.051)	(.052)
	Cz												
	C4	-.127	-.160	-.160	-.162	181	.121	.171	.171	244	.232	.249	.254
		(.039)	(.043)	(.043)	(.048)	(.042)	(.046)	(.054)	(.004)	(.051)	(.048)	(.050)	(.052)

Table 3. 3. Means and standard errors of the amplitudes for N1, VPP and P300 for chimeric faces condition: chimeras with emotion presented in the left (LVF) and right visual field (RVF).

Early temporal window (80-120ms): N1:

In the time window most closely resembling the N1 effect, we observed a significant interaction between group, visual field and both of the electrode levels, *F* (1, 28) =4.548, *p* = .042, η^2 = .140. The interaction between group and visual field was maximal (greater F value) over the frontal electrodes, *F* (1, 28) = .1.457, *p* = .238, η^2= .049 but did not reach significance. Pairwise comparisons of the simple effects showed that the two groups had different amplitudes across the two visual fields: the group with the relative right-ward visual field bias showed more negative N1 effect when the emotion was presented in the right relative to the left visual field, M (SE) = -.107 (.035) versus -.099 (.033), respectively. By contrast, the group with the relative left-ward visual field bias showed more negative N1 effect in the left, relative to the right visual field M (SE) = -.104 (.033) versus -.079 (.033), respectively, but none of the effects was significant, p values >.372.

Due to our expectation, we looked at pairwise comparisons between the two hemispheres in the two groups. Only the RH laterality groups appeared having significantly different amplitudes across the two hemispheres, but, importantly, in opposite direction: the RH laterality group with the relative left-ward visual field bias showed a greater negative N1 effect over the right hemisphere, relative to the left hemisphere, M (SE) = -0.158 (.046) versus -.095(.040), respectively, p = .002. In the LH laterality group, the differences across the two hemispheres did not reach significance, p= .129.

Emotion also significantly interacted with the hemispheres, *F* (1, 28) = 4.658, *p*=.040, η^2 =.143. This was because both happy and sad chimeras showed a much greater differential effect across the two hemispheres with amplitudes being significantly greater over the RH than the LH (M (SE) = -.132 (.032) versus -.101 (.029) and -.172(.032) and -.111(.025), respectively, p values < .026.

Middle window (130-180ms), VPP:

In the time window most closely resembling the VPP effect, we observed a significant interaction between emotion, visual field, electrodes and hemisphere, *F* (1, 28) = 7.762, *p*= .009, η^2 = .217. The interaction between emotion, visual field and hemisphere was significant over the frontal sites, *F* (1, 28) = 8.005, *p*= .009, η^2 = .222, but not over the central sites, *F* (1, 28) = .021, *p*= .887, η^2 =.001. In turn, this effect over the frontal sites was because there was a visual field by hemisphere interaction for the sad chimeras *F* (1, 28) = 8.829, *p*=. 006, η^2 =. 227 but not for the happy chimeras, *F* (1, 28) = 1.540, *p*=. 224, η^2 =. 049. When the sad emotion was presented on the LVF, the amplitudes were significantly greater over the RH, relative to the LH (M (SE) = .092 (.042) versus -.001 (.002), respectively, p = .037). By contrast when the emotion was presented in the RVF, the amplitudes were not significantly different over the LH than the RH (M (SE) = .126 (.030) versus .105 (.036), respectively, p = .389, see Figure 3.3). Furthermore, the amplitude difference between the LVF and RVF emotion presentation was only significant over the left hemisphere, p < .001, with RVF presentation eliciting greater amplitudes than LVF presentation indicating interhemispheric transfer of the emotion information from the receiver left hemisphere to the right hemisphere

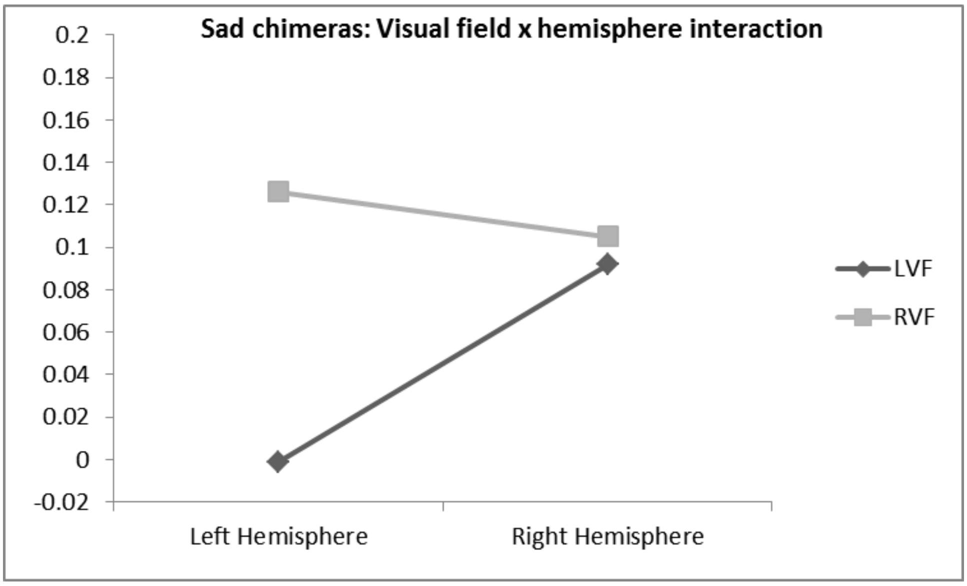

Figure 3.3. Sad chimeras: Visual field of presentation x hemisphere interaction

Late window (180-400ms), P300:

In the time window most closely resembling the P300 effect, we observed a significant interaction between visual field by laterality group and electrodes, *F* (1, 28) = 5.781, *p*=.023, η^2 =.171. Also there was an emotion by hemisphere and electrodes, *F* (1, 28) = 4.937, p = .035, η^2 =.150.However, none of the follow-up statistics were significant, and as such it is very difficult to establish the reason for these interactions.

Importantly, there was a significant interaction between visual field, and hemisphere *F* (1, 28) = 4.200, *p*=.050, η^2 =.130. Pairwise comparisons of the simple effects showed that both, left and right visual fields appeared having significantly greater amplitudes over the LH relative to the RH, p values < .049.

Summary of the chimeric face electrophysiology results:

Early in the epochs, the amplitudes that we recorded were sensitive to the emotional content of the chimeric faces presented. Both, the happy and sad chimeras showed an asymmetry between the left and right hemisphere amplitudes; specifically this greater difference appears to be driven by a difference over the right-hemisphere recordings. Importantly, this early lateralised effect was modulated by laterality group, where those participants with a left-ward visual field bias showed greater amplitudes over the right-hemisphere, whereas the participants with a right-ward visual field bias did not show any difference.

Midway through the epochs (130-180 ms) the chimeras face trials demonstrated that the effect of emotional content could be relatively lateralised, depending upon the visual field of the emotional content. Specifically with sad chimeras, when the emotional content was presented on the left visual field, we observed more positive amplitudes over the right hemisphere than the left, whereas when the emotional content was presented on the right visual field, we observed the opposite pattern, however, no significant.. There was no significant effect with happy chimeras.

In the final period of the epoch (180-400 ms) with the chimeric faces, there was not a strong differential response to the two emotions. However, there was a different effect of visual field of emotion presentation over the two hemispheres: when the emotion was presented in the LVF in comparison to when presented in the RVF there were greater amplitudes over the left hemisphere.

3.1.3 Discussion

The study aimed to investigate the patterns of electrophysiological responses of early emotional processing at frontocentral sites and whether these become lateralised. Most importantly, the present study aimed to find neural correlates of the chimeric faces task as a test of laterality. The data show a pattern of waveforms consistent with previous EEG research for the processing of emotions, namely, the N1, the VPP and the P300. Findings are discussed for the standard faces condition first followed by discussion of the findings for the chimeric faces task.

Standard Faces

Early temporal window: N1 (80-120ms)

In the first window the first measurable electrophysiological event over frontocentral sites was a N1 showing a large negativity at about 100ms poststimulus. The N1 appeared to be modulated by emotional expression as it did vary significantly between the happy and sad emotions but not between the happy, sad and neutral expressions. These findings are consistent with previous studies regarding the main ERP responses observed. Marinkovic and Halgren, (1998) and Wong et al. (2009), for instance, found an early negativity N1 peaked at 110ms after stimulus onset and its amplitude was larger at frontocentral sites (Fz, Cz, F3, F4, C3, C4).

There are some other studies, which instead of the frontocentral N1, report its reverse polarity counterpart at occipital sites, the P1. These N1/P1 are thought to indicate the same processes (Campanella et al., 2002). This P1/N1 component has been identified as the earliest indication of processing of visual stimuli, where processing occurs as early as 100ms. Activation of extrastriate visual cortex, where attentional modulation and detection of physical features of the stimuli occurs, has been proposed as the origin of P1/N1. The P1/N1 does not appear to be face-specific (Rossion et al., 1999b); however, there is evidence indicating that the global processing of faces, recognition of facial structures as well as detection of configural changes such as those appearing with face inversion, may also be reflected in these early responses (Itier & Taylor, 2002).

The modulation of N1 by emotions in this study indicates that this primary visual process reflects a rapid and automatic encoding of facial expressions, which occurs independently and in parallel with face processing. This is what one would expect from an evolutionary perspective, but researchers hold differing views on this perspective. For instance it was argued that P1/N1 is taking place too ‘‘early’’ and it was expected not to be modulated by facial expressions (Campanella et al., 2002). There has been evidence, however, suggesting that the facial expression affects the very early stages of face processing as well as the later cognitive processing of faces (Batty & Taylor, 2003; Campanella et al., 2002; Eimer et al., 2003; Esslen, et al., 2004; Marinkovic & Halgren, 1998; Vandeerploeg, Brown & Marsh, 1987). In addition to the aforementioned studies, distinction of neutral from emotional facial expression has been reported from 110ms by Krolak-Salmon et al. (2001) and Pizzagalli et al. (2002). It appears therefore that facial expressions are processed earlier and independently of global facial encoding, followed by a crude configuration of facial features. This discrimination of emotional information from faces at such an early stage is supported by the face processing model put forward by Bruce and Young (1986) which postulates that the structural characteristics of a face (which enable somebody to distinguish a face from other objects) are processed separately and independently from the semantic information from faces; such as emotion expression. This study found no discrimination between emotional (happy and sad) and non emotional (neutral) faces at N1; however, there was evidence of valence discrimination between happy and sad faces. Discrimination of valence of the emotions would be expected at a later stage of processing (around 300ms).One can, however, argue that this result is due to the direction of attention to emotion from the task and thus emotion was processed rapidly. The latter was suggested by Mangun (1995) who showed that P1/N1 ERP is an attention sensitive component. Magnum (1995) showed that visual selective attention improves perception as it modifies sensory inputs at an early stage of processing to higher stages of perceptual analysis. This could be the case for the present study as participants completed an explicit emotion task where the attention is placed on the emotion.

The present study appears to have replicated the early processing of emotional information from faces, as the N1 was found to be modulated by emotion. This effect at frontocentral sites seems to suggest an early rapid and automatic encoding of emotional facial expressions in line with an evolutionary perspective and previous research. N1 was followed by a VPP at 130-180 ms which is considered specific to structural encoding of faces.

Middle temporal window: VPP (130-180ms)

Separation of the two processes (structural encoding of facial features and emotional processing) reported above are observed also at a later stage, over the VPP (polarity reversed counterpart of N120) which also was modulated with emotion. This finding is in line with research by Batty et al., 2003; Blau et al. 2007; Pizzarelli et al., (2001) which also showed that emotional processing is still ongoing independently even at N170/VPP where it is a stage of structural decoding of facial stimuli just before the identification of a face occurs (Bentin, Sagiv, Mecklinger, Friederici, & von Cramon, 2002). However, it is inconsistent with Holmes and Eimer (2002) who did not find any modulation of the N170 with emotion. The inconsistencies in the findings might be due to the different tasks utilised. Holmes and Eimer (2002) used a task, which required a shifting of attention from an emotional face to a house. The present study did not look at explicit attention differences, and it used an explicit emotion recognition task where the emotional expression was always relevant to the task.

Late temporal window: P300 (180-400ms)

The long latency (>300ms) processes are thought to reflect a higher and more intensive level of emotional processing; for instance, conscious evaluation of emotional information and memory updating. A number of studies have been consistent in finding an enhanced positivity (or reduced negativity) at these later latencies within the frontocentral sites (e.g., Batty et al., 2003; Eimer et al., 2007; Olofsson et al., 2008; Vandeerploeg et al., 1987). In fact, findings support the idea that the long latency processes (>300ms) are reflected in a sustained positivity, which is involved in memory updating. There are a number of studies on emotional memory which postulate that unpleasant and pleasant (arousing) stimuli elicit greater positive ERPs compared to neutral stimuli in this late time window and that this larger positivity was associated with an improved memory performance of these stimuli compared with neutral ones (Dolcos and Cabeza, 2002; Palomba et al., 1997). The present study indicates this tendency and one can argue that it fits well with this research as indeed the amplitudes of P300 beyond 230ms was greater for sad and happy stimuli than for neutral.

The results of the present study suggest a two-stage pattern of responses to happy, sad and neutral facial expressions. A very early stage where the more arousing faces (happy) are differentiated from less arousing emotional faces (sad/neutral) and a later differentiation between the three facial expressions with sad having the greater amplitudes (Heilman, 1997). Two stages of emotion processing have also been reported by Carretie et al., (2006) and Vandeerploeg et al., (1987); however, the exact pattern of processing is different to present findings as different methodologies were applied.

As far as laterality is concerned the present study found that the processing of facial expressions started with a significant bilateral activation for all emotions which was sustained until 400ms. Perhaps after the time window examined in this thesis (later than 400ms), there is a shift of advantage towards the RH or the LH. Carbary et al. (2001) suggested that the difficulty of the task (as indeed is the cognitive processing of facial emotion and preparation for response) causes a shift to feature analysis by the left hemisphere. A left hemisphere advantage could also be expected by the response demands with the right hand which would increase the left sensorimotor cortex activation. We did not find any shift of laterality. However, an expected right hemisphere advantage could possibly occur at later latencies, beyond 400ms which we did not look at.

Chimeric Faces

The main aim of the present study was to document the physiological correlates of the Chimeric Faces Test as a test of laterality in emotion processing. The present data give indication of patterns of lateralised activation, which were associated with the specific visual fields of emotion presentation, which is discussed below in more detail.

The two groups of participants differed in the amplitudes across the two hemispheres but in opposite directions: the RH laterality group with the relative left visual field bias showed a greater activation in the right, relative to the left hemisphere whilst the group with the relative right visual field bias showed a greater activation in the left, relative to the right hemisphere. This effect depended on the visual field of emotion presentation. This means that participants, with the bias to choose, as more emotional, the chimeras which had the emotion in the LVF, had greater activation in the RH whereas participants with the bias chose, as more emotional, the chimeras with the emotion on the RVF had greater activation of the LH. This finding provides us with an indication of the neural markers of the lateralization observed in behavioural studies which used CFT as a test of laterality (Bourne, 2010; Kucharska-Pietura & David, 2003; Levy et al. 1983). The fact that the interaction between the visual field presentation of the emotion and the hemisphere in the present study did not reach significance can be explained by the differences between these studies and the present in the administration of the CFT. In Bourne, (2010) for instance, the pair of chimeras was placed one above the other; whilst in the present study one chimera in the pair was followed by its mirror chimera. Phillips & Channon (2008) showed that decoding emotions from faces places high demands on working memory. Perhaps two faces in succession intensify these demands and have an effect on the processing.

Furthermore, this study found that the amplitudes elicited by sad chimeras differed across the two hemispheres depending on the visual field of emotion presentation: when a sad chimera was presented to the left visual field elicited greater amplitude over the right hemisphere relative to the left hemisphere, whilst when a sad chimera was presented to the right visual field elicited greater amplitude over the left hemisphere relative to the right hemisphere. This finding implies that behavioural evidence of hemispheric bias when presenting an emotion to the left or right visual field has a neurophysiological correlate. In other words, this finding indicates the neural correlates of the visual field bias established with behavioural measures of lateralisation for emotion processing which used CFT as a test of laterality

In summary, this study found the main potentials indicated by previous EEG research for the processing of emotions. Namely the N1, the VPP and a later positivity at ~200-400ms, the P300. These potentials seemed to be modulated by emotional expressions which supports the idea that the recognition of emotion from faces and structural encoding of faces are parallel and independent mechanisms. Most importantly, in the chimeric faces condition, we found that electrophysiological activity was consistent with the visual field bias of the two laterality groups, in that the RH laterality group with the relative left-ward visual field bias showed greater amplitudes over the RH when the emotion was presented in the left visual field. These findings are very important indicators of the chimeric faces test as a test of laterality. With regards to the visual fields of emotion presentation, this finding provides us with evidence of the neural markers of the lateralisation observed in behavioural studies.

3.2 Study 2: Developmental trends in lateralisation

Behavioural investigations in emotion recognition skills in children propose that understanding of emotions from facial expressions is an ability that develops between 4 and 11 years old and that different emotions are recognised at different stages of development with happy recognised the earliest, followed by sadness or anger, surprise or fear, and disgust (e.g., Durand et al., 2007; Herba & Phillips, 2004; Reichenbach & Masters, 1983; Vicari, et al., 2000; Widen & Russell, 2003). Individual differences in children’s social experiences and interactions have been used to explain the variability in facial expression recognition skills in children (Camras et al., 1990; Gordon, 1989). Moreover, recently, researchers have been exploring the role of maturation of the brain structures to explain the development of emotion understanding in children. Whilst research with adults has extensively explored how emotion is processed in the brain, the findings presented in study one were the first to investigate laterality in neural activation. Importantly, lateralisation for emotion processing in the brain has not been researched with children to explore the development of hemispheric lateralisation for emotion processing. Therefore, there is no investigation of whether the variability and development of emotion recognition skills map onto neural development as suggested by the model of Boles et al. (2008, chapter 1).This study focuses on laterality developments in the brain during middle childhood and late childhood using ERPs for facial emotion recognition.

Study 1 demonstrated that the emotional chimeric faces are images that produced laterality effects in the brain, indicating the CFT as a test of laterality. However, we do have evidence of neural developmental trends for the processing of emotions. The limited evidence we have so far for hemispheric asymmetry development comes from behavioural studies.

Several studies using chimeric faces tests with children as young as 5 years old showed that the lateralisation of emotion processing develops (Chiang et al., 2000; Levine & Levy, 1986; Watling & Bourne, 2007; Workman et al., 2006). These studies suggested that while young children are lateralised for emotion processing, this lateralisation continues to strengthen and becomes established between 5 and 10 years. At 10 years the asymmetry typically stabilizes to an adult level.

Further evidence showed that the right hemisphere asymmetry differs for different facial expression processing (Workman et al., 2006; Chapter 1). For instance recognition of happiness is right lateralised from an early age (5-6 years), laterality of sad was marginally different between 5 and 10 year olds, fear was right lateralised in the 10-11 age group, surprise and disgust at the age of 7-8 years and anger at the age of 10-11 years.

In chapter 2 it was discussed that the ERP methodology has been described by Batty & Taylor (2006) as the most child friendly of the neuroimaging methods to investigate neural development; in this study 2 therefore, will use this to investigate cerebral lateralisation of emotion processing in young children. Additionally, EEG provides the best means to complement behavioural studies (Taylor & Pang, 1999). As such, exploring children's ERP activation to facial expressions of emotion may explain some of the variance in children's emotional processing across development. However, the number of ERP studies to investigate brain electrical activity in young children, and whether there are any differences with development is very few. Importantly, no study has explored laterality in emotion processing.

Kestenbaum and Nelson (1992) is one of the few ERP studies with children which examined electrophysiological differences between 7 year olds and adults when they completed an explicit emotion recognition task. Children were presented with happy and angry faces. The task required that children press a button when they see a happy or angry face. They found that children responded differently than adults to happy and angry facial expressions of emotion. They reported greater amplitudes and shorter latencies for adults when a happy expression was the target, rather than when an angry was the target. In contrast, for children the amplitudes were greater for angry expressions than for happy. They also found a difference between the activation of the two hemispheres. The responses were lateralised, for adults only, with the activity being greater over the RH. More recently, Batty and Taylor (2006) examined the development of the processing of facial emotional stimuli across a wider range of ages (children 4 to 14 years old) by investigating the early ERP responses to the six basic emotions in an implicit emotion task, where emotional faces were presented in blocks and children were instructed to press a button when they saw a non-face object (so children were not asked to attend to the emotional information in the face). They found developmental changes in the latencies, amplitudes and scalp topography of responses to the six basic emotions and neutral faces across childhood. The amplitudes decreased (the wave was smaller) with increasing age which Batty and Taylor suggested indicate a continuous automatisation of the processing which resulted in a progressive decrease in cortical activation. It is likely that developmental changes in synaptic density, myelination, and other changes, for instance, changes in skull thickness, may affect amplitude changes across age. Furthermore, there were amplitudes differences in the ERPs produced for different emotions. For instance, happy faces produced smaller amplitudes than disgust and sadness within 360-390ms window. Latencies were sensitive to emotions in the young children. Happy faces, for instance, had shorter latencies than the negative emotions. These effects of emotions on latency were thought by the researchers to suggest different rates of processing of different emotions during development, as the processing of emotions becomes more rapid and more automatic with age. Whilst now the focus is more and more on the physiological investigations of the development of facial emotion processing no study thus far has focused on hemispheric laterality patterns in the first 400ms of processing.

Study 1 with adults above identified the early ERP deflections during emotion processing from 100 ms to 400 ms poststimulus, but most importantly, it gave indications of the neural correlates of the CFT test of laterality using an explicit emotion task. If laterality effects are evident so early in the processing of emotions in adults, studying the developmental course of this laterality at a neurophysiological level not only will provide insights into the development of the various stages of emotional processing but it will also enable us to extrapolate to the behavioural evidence of emotional development. The present study examines the development of hemispheric asymmetry of children in middle childhood (5- to 8-year olds) and late childhood (9- to 13-year olds) and asymmetry in a comparison group of adults. The literature suggests that laterality for emotion processing develops between the ages of 5 to 10 year olds (Workman et al., 2006). Additionally, the present study explored the development of laterality when children performed an implicit emotion recognition task. Implicit tasks provide a useful index of development of connections between amygdala and prefrontal cortex (section 2.3.4). If these connections between cortical areas and subcortical structures become further refined (Herba and Phillips, 2004), we wanted to see if laterality affects emotion processing above and beyond the direction of attention to emotion or not.

The study aims to investigate the patterns of electrophysiological responses of three age groups, one middle childhood, one of late childhood and one comparison group of adults. The interest was in the same electrophysiological responses as in study 1 during the early 400ms of emotional processing at frontocentral sites, at what age these characteristic electrophysiological responses develop, whether they become lateralised, and finally the trajectories of this development. Most importantly the focus was whether the laterality effect seen in the explicit chimeric faces test is observed also in an implicit chimeric faces test. It was expected to find age-related changes in the ERP components. Although not much work has been done with children, existing work indicates that ERPs in typically developing children might indicate decreased amplitude with age (Parker & Nelson, 2005). Most importantly, the primary aim of this study is to investigate the ERP responses to chimeric faces, to determine whether the processing is affected by the visual field of emotion presentation and whether there are age related differences in the processing. The findings of study 1 encourage us to think that the pattern of laterality development reported by behavioural studies (chapter 1) should be evident in the physiological recordings in this study.

3.2.1 Methods

Participants

A total of 87 children (53 males, 34 females) and 35 adults (9 males and 26 females) participated in the study. The child participants were classified as being in one of two age groups: middle childhood and later childhood; thus there were three age groups. Forty six 5- to 8-year-olds were in the middle childhood age group, (M=6.74, SD=1.1), forty one 9- to 13-year-olds were in the late childhood age group (M=10.24, SD=1.1), and thirty five 19- to 42-year-olds were in the adult age group (M=23.11 years, SD=5.9). The participants were approximately 95% White British and 5% other. Child participants performed three practical tasks that were used to assess handedness (2.2.1). Children were presented with a piece of paper and asked to write their name on this and then to cut the paper in half. Finally children were seated in front of a computer and provided with the mouse centrally positioned. The experimenter documented which hand each participant used to write his or her name, to cut the paper, and to use the mouse. If for all three tasks the right hand was used, the child was considered right handed and their results were included in the analyses.

All adults participants were right-handed by self-report and this was confirmed by a handedness questionnaire (adapted from Dorthe, et al., 1995). As explained in section 2.2.1, the questionnaire was comprised of 17 items, each measured on a seven-point Likert scale form -3 (always with the left hand) to +3 (always with the right hand). The scores were summed to obtain a handedness score ranging from -51 (strongly left handed) to +51 (strongly right handed). Thirty two participants reported to be right handed. These had a mean score of 37.1, SD (6.9), range from 21 to 51. All the children were typically developing and all participants reported having normal or correct to normal eyesight, were not on any medication that would influence performance, and did not have any known brain damage. Participants were fully informed as to the nature of the study and provided written informed consent.

Child participants were recruited from local state primary schools in a middle class area of Surrey, South East England. Flyers were sent home through the schools and parents who were interested to participate contacted our lab and made an appointment. Children who attended the appointment were given £15 pounds for their time and their travel expenses. Adult participants were recruited through the Research Participation Scheme of the Department of Psychology, Royal Holloway, University of London. Most were students and were given course credit for their course and some were paid. Some adults were postgraduates who volunteered to participate. The literature justifies the group division: both, hemispheric assymetry as well as accuracy recognition for sad expressions have been reported to significantly develop around the age of 10 year olds (Chiang et al, 2000; De Sonneville et al., 2002; Workman et al., 2006). The participants were given information about the study and assented to participate. They were advised that they could stop at any time. All parents signed an opt-in form. This study was approved by the Ethics Committee of the Department of Psychology of Royal Holloway, University of London.

Materials

The stimuli used were black and white photographs of NIMH (National Institute of Mental Health) pictures of males and females, previously validated in chapter 2, and the same used in study 1, displaying emotional facial expressions happy, sad and neutral. All faces were posed in full frontal orientation. These will be referred to as standard faces. The stimuli were framed with a black oval mask to remove additional features such as hair and ears, thereby allowing children to focus on the internal features of the face and emotion. In total there were 51 pictures (17 pictures for each of the three expressions). The study was designed to use as many identities possible to make sure any effects were from the facial expression and not the face. Fifteen happy, 15 sad faces and the neutral ones of the same identity as the emotional faces were chosen from the validated faces (see Section 2.4.1). From these, 9 were faces of a male and 6 faces of a female.

Standard faces stimuli. These were each of the 15 standard happy faces, 15 sad faces, validated in Section 2.4.1, and the 15 neutral faces for each or the 15 happy and 15 sad identities which was validated as happy and sad.

Chimeric Faces stimuli. From these validated standard faces, the chimeric faces that were developed for sad and happy emotional expressions were used (see Section 2.4.2), where one side of the face displayed an emotion (either happy or sad) and the other side was neutral. In total there were 60 chimeras (15 happy with the emotion on the left side of the face, 15 sad with the emotion on the left side of the face and their mirror images where the emotion was on the right side of the face).

Procedure

Participants were all invited to the EEG lab within the Psychology Department. Electrodes were placed on their head frontocentrally according to the 10-20 system, as outlined in section 2.3.2: three frontally, over left, right hemispheres and midline, the F3, F4 and Fz, respectively; three central electrodes over left, right hemispheres and midline, respectively. For the EOG two electrodes were placed at the outer canthi of each eye. For reference two electrodes were placed behind the mastoid bone of each ear and one ground electrode was placed on the nasion-inion axis between the Fz and Cz electrodes. Each participant was seated in a dark room and a 17”computer screen was placed at a viewing distance of 70cm. Their head was comfortably positioned with their chin in a chin rest. They were instructed to sit still and maintain central fixation during passive viewing of stimulus presentation. There was a curtain that was drawn across the room to separate the participant and the experimenter to reduce distraction.

Participants performed two tasks whilst having their electroencephalogram (EEG) recorded: i) a standard faces viewing task and ii) a chimeric faces viewing task (CFT). These tasks were randomised for each participant as to which was first and second.

Within each task the stimuli were presented for 700ms at the centre of the computer screen in a random order and without immediate stimulus repetition of the same stimulus. The interstimulus interval was 2s. The standard faces viewing task had 234 trials, and the chimeric faces viewing task had 324 trials. There was a short break between the two tasks. Each stimulus in both tasks was succeeded by a circular fixation point, which sometimes, randomly, would transform in to a square. Participants were instructed to maintain central fixation at all times, watch the stimuli and when the fixation point was a square rather than a circle press the spacebar on the keyboard. This task was intended to maintain the child's attention towards stimulus presentation. As this was designed to be an implicit emotion processing task, attention was not directed towards the emotional faces, unlike the task in study 1 which was an explicit emotion task (discussed in section 2.3.4).

ERP Recording and Analysis

As highlighted in section 2.3.2, ERPs were recorded with Ag-AgCl electrodes and linked-mastoid reference from Fz, F3, F4, Cz, C3, and C4 according to the 10-20 system, with a sampling rate of 1000 Hz, and a band-pass filter of 0.01 Hz. Horizontal EOG was recorded bipolarly from the outer canthi of both eyes. The impedance for all electrodes was kept below 10 KΩ.

All recordings were analysed and processed off-line after data acquisition. EEG and EOG were epoched off-line into 500-ms periods and starting 100ms pre-stimulus and ending 400ms post-stimulus onset. Epochs with artefacts, mainly eye-blinks, were excluded from the analysis after visual inspection of the raw data. Each participant included in any ERP waveform had at least 30 individual waveforms per average.

For the standard faces there were three conditions: happy, sad and neutral. For the chimeric faces there were two conditions: happy and sad. Analyses were conducted on the ERP responses to each face. Separate averages were computed for all conditions; happy, sad, neutral, chimeras with the happy or sad on the right side of the face and chimeras with happy or sad on the left side of the face. These were calculated for each participant and for the six electrodes sites (F3, Fz, F4, C3, Cz, C4), culminating in the calculation of grand averages for all participants in each condition. The grand averages from the standard face trials were analysed using mixed ANOVAs with age group x expression (happy, sad, neutral) x hemisphere (left, middle, right) x electrode site (frontal, central) as factors. Any significant interactions were followed-up using low-level ANOVAs, and ultimately pairwise comparisons to establish the reason for the original interaction.

The data of the chimeric faces task were also submitted to repeated measures mixed ANOVA with age group x emotion (happy, sad) x hemisphere (left, right) x visual field presentation of emotion (LVF, RVF) x electrode site (frontal, central) as factors. For the chimeric faces task only two levels of the laterality factor were used (right and left hemisphere). This was because in the chimeric faces task the main focus was the interaction between the visual field of the emotional content and the hemisphere of the electrophysiological recording. Throughout, type 1 errors associated with inhomogeneity of variance were controlled by using the Greenhouse-Geisser epsilon where appropriate (Jennings and Wood, 1980).

For all of our ANOVAs, we performed the analysis on three separate time windows, ranging from 80-120ms, 120-180ms and 180-400ms. The general cortical response included a prominent, early negative peak between 80-120ms, a subsequent positive peak from 120-180ms and later positivity from 180-400ms. Whilst it might not be helpful to assign labels to these windows (as these labels often come with their own functional interpretations), these are analogous to the N1, VPP and P3 that others have previously described. (e.g. Joyce and Rossion, 2005; Picton, 1995).

3.2.2 Results

Standard faces

Early temporal window (80-120ms):

Grand averages over the six electrode sites for each group are presented in figure 3.6 (5-8 years group), figure 3.7 (9-13 years group) and 3.8 (adults). In the time window most closely resembling the N1 effect, it was observed a main effect of age group, *F* (2,110) =3.887, *p*=.023, η^2=.066. Pairwise comparisons with Bonferroni corrections showed that the amplitudes of N1 were significantly greater for the middle childhood group than adult, M (SE) =-.573 versus (.043), -.391m versus (.051), *p*= .020, respectively, but not between the two children groups nor between the late childhood children and adults, p values >.382. Overall, the amplitudes decreased with increasing age (Figure 3.4). There was a significant main effect of hemisphere, *F* (1.567, 172.420) = 29.272, *p*< .001, η^2= .210, with the amplitudes being significantly greater over the midline electrodes relative to either left or right-hemispheres electrodes (M (SE) = midline -.529(.029), LH, -.464(.027), RH, -.448(.026), *p* values < .001). The left and right-hemisphere electrodes did not differ from one another, *p* = .690.

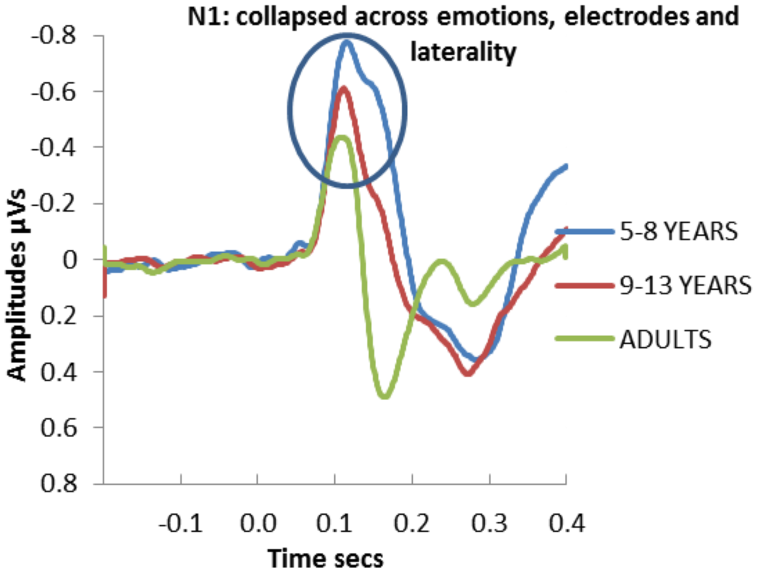

Figure 3.4. N1: Grand Averages of three age groups collapsed across emotions, frontal and central electrodes and across hemisphere location (left, central, and right electrode locations)

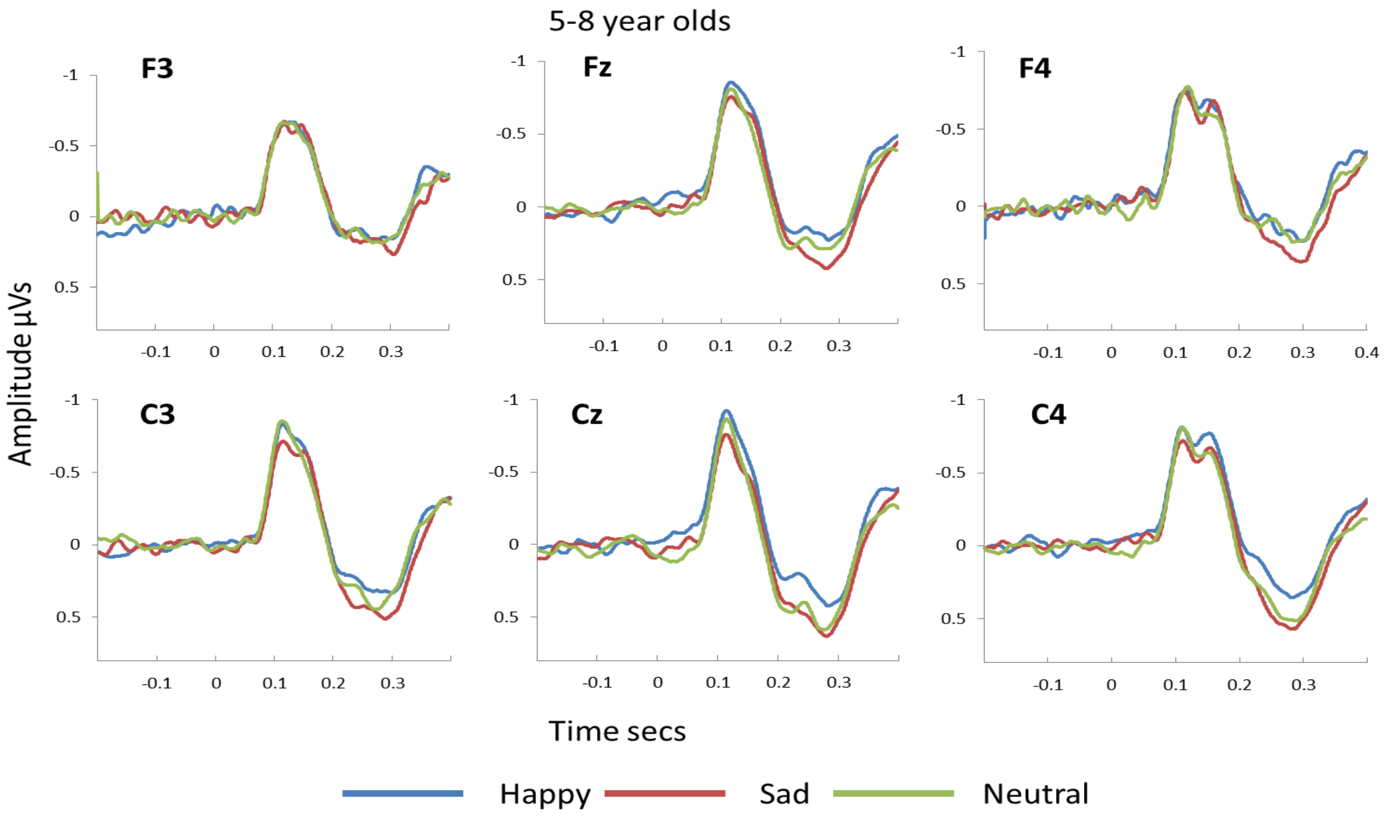

Figure 3. 5. Grand Averages of middle childhood group, for happy, sad, neutral faces over all electrode sites.

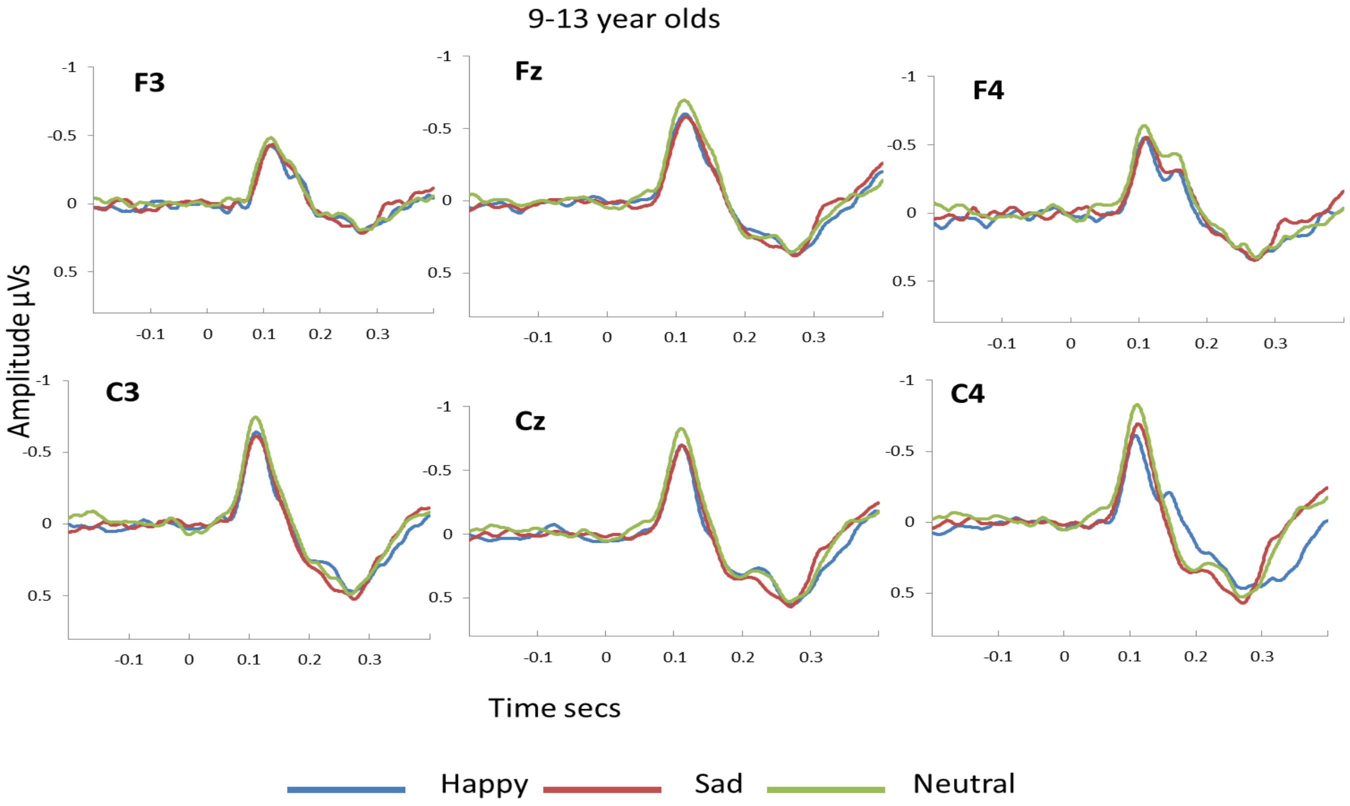

Figure 3. 6. Grand Averages of late childhood group, for happy, sad, neutral faces over all electrode sites.

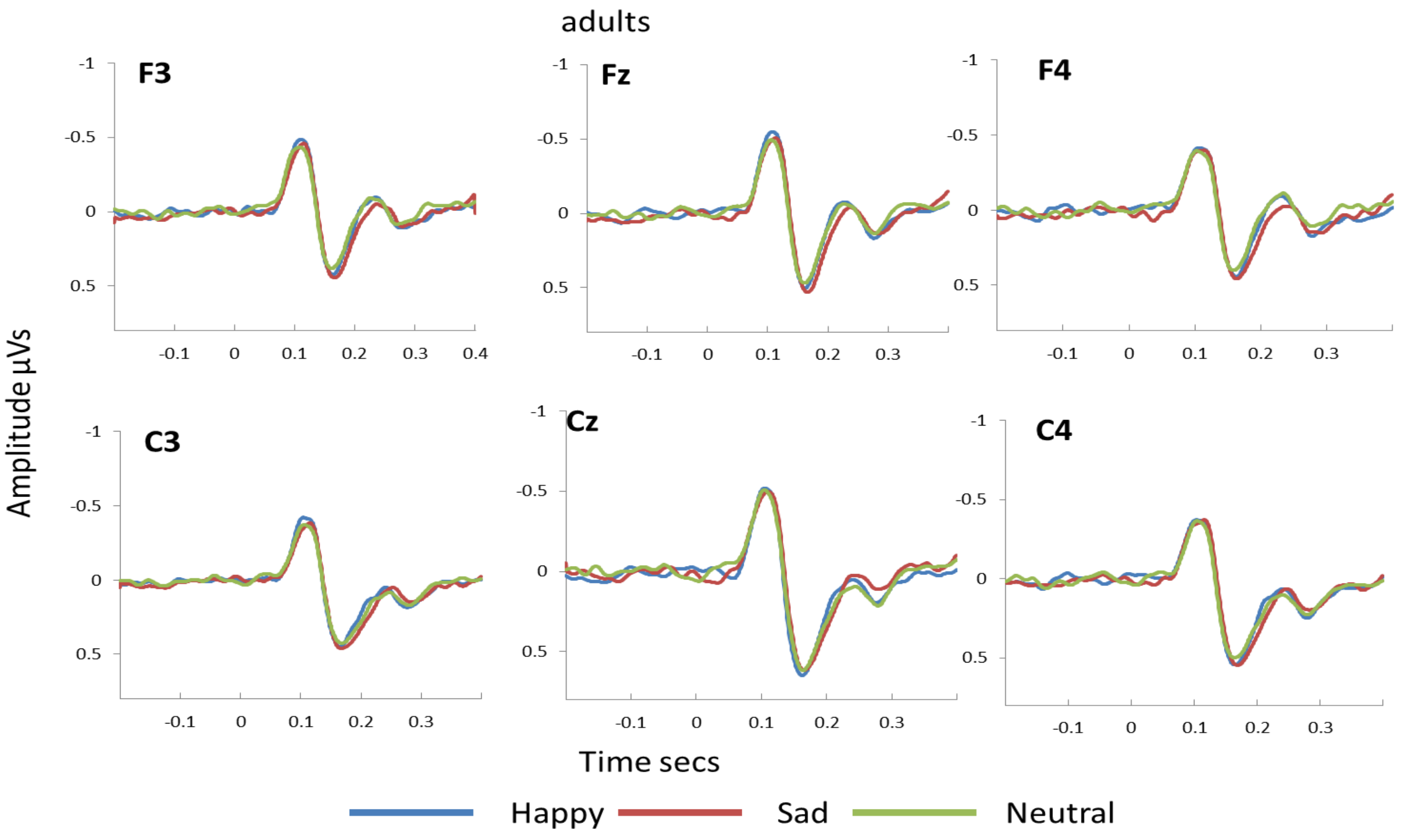

Figure 3. 7. Grand Averages of adult group, for happy, sad, neutral faces over all electrode sites.

Middle window (130-180ms):

In the time window most closely resembling the VPP effect, it was observed a main effect of age group *F* (2,110) =3.028, *p*<.001, η^2= .307. Planned comparisons showed that the amplitudes of VPP were significantly different between both children's groups and adults, M (SE) =-.257 (.053) versus -.043 (.057) versus .320(.063), p values <.001, respectively, and between the middle childhood group and late childhood children groups, *p* =.022. The positivity increased with increasing age (Figure 3.5). It was also observed a significant interaction between hemisphere and age group, *F* (3.765, 207.048) = 3.009, *p* =.022, η^2=.052. Pairwise comparisons, Bonferroni corrected, indicated that in the middle childhood group there were significant differences between the LH versus midline, M (SE)= -.267(.055) versus -.181(.053), *p*<.001 , RH versus midline, M (SE)= -.321(.055) versus -.181(.053), *p*<.001 and LH versus RH, M (SE)= -.267(.055) versus -321(.055), p=.026. A similar pattern was seen for the late childhood group, (LH versus midline, M (SE) = -.043(.059) versus .027(.057), p =.001, RH versus midline, M (SE) = -.114(.055) versus 027 (.057), p=.001) and LH versus RH (M (SE) = .043(.055) versus -114(.059), p=.005). In the adults group there was a significant difference only between the LH versus midline, M (SE) = .291(.065) versus 366(.063), p=.002, and RH versus midline (M (SE) = .302(.065) versus 366(.063), p=.005). There was no significant difference between the LH and RH, *p* = 1, Figure 3.8 a, b.

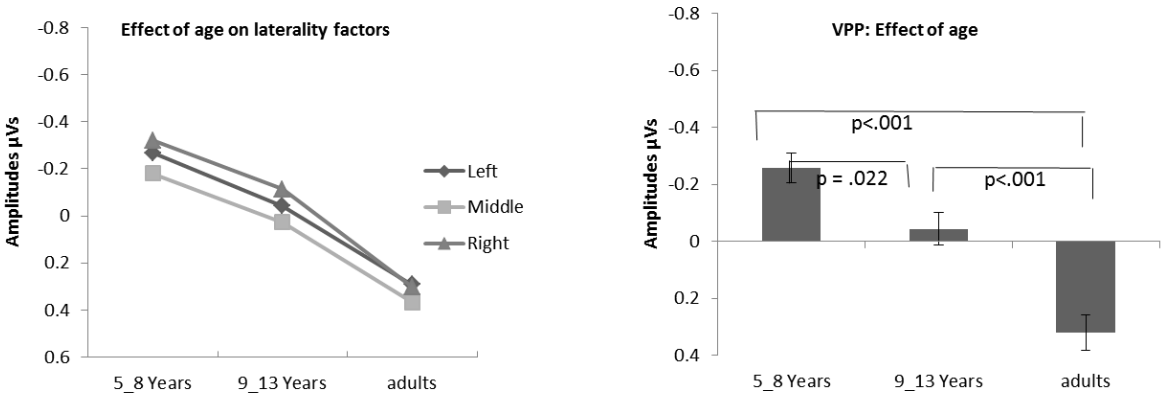

Figure 3. 8. VPP: a) The effect of age on the laterality factors (left hemisphere, central and right hemisphere) and b) age group differences

Late window (180-400ms), P300:

In the time window most closely resembling the P300 effect, it was not found main effect of age group, *F* (2,110) = 1.324, *p* =.270, η^2=.024. It was observed a significant main effect of emotion, *F* (1.336, 146.970) = 14.155, *p*<. 001, η^2= .114, with amplitudes being significantly different between happy and sad (M (SE) = .089(.033) versus -.091(.036), p<. 001) and between neutral and sad faces, M (SE) = .099(.039) versus -091(.036), p<. 001 shown by pairwise comparisons. The difference between neutral and happy faces was not significant, p = 1 (Figure 3.9a).

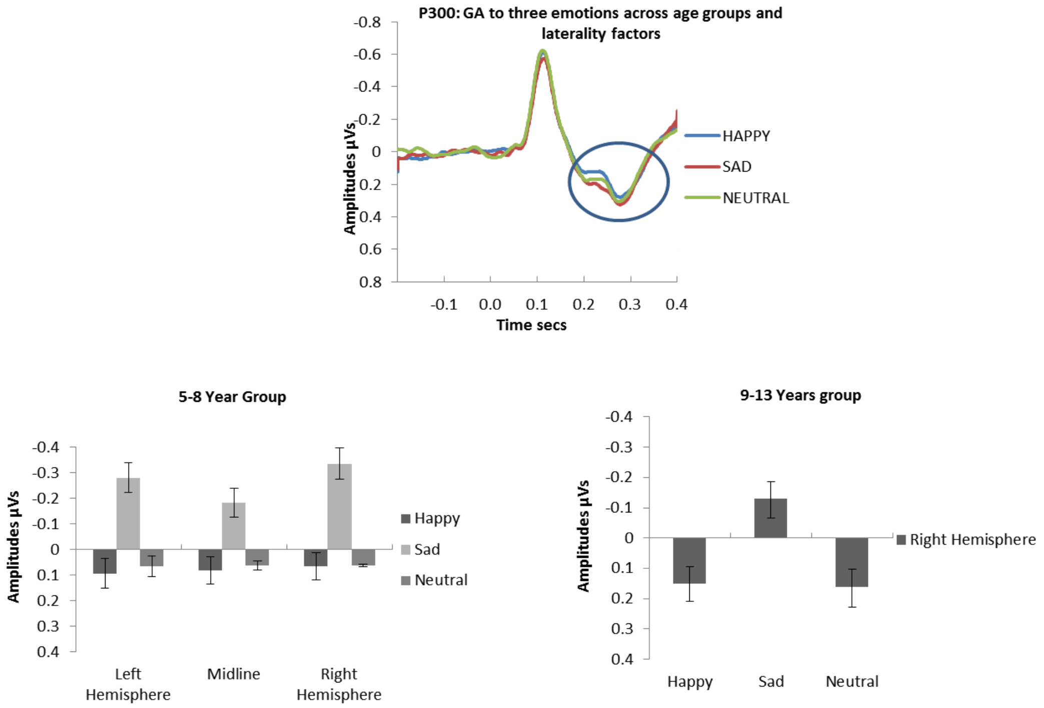

Figure 3. 9. P300: a) Grand Averaged ERPs for happy, sad and neutral conditions collapsed across age groups and laterality factors (top), b) differences between 3 emotions over laterality factors in middle childhood group and c) differences between 3 emotions over right hemisphere in late childhood.

We found a significant three-way interaction of emotion x hemisphere x age group, *F* (6.164, 339.007) =2.986, *p*=. 007, η^2= .051. The age group x emotion was significant over the LH, *F* (2.878, 158.285) = 4.563, *p*= .005, η^2= .077 and over the RH, *F* (2.611, 143.631) = 6.054, *p*= .001, η^2= .099 but not over the midline electrodes, *F* (2.743, 150.891) = 2.581, *p*= .061, η^2= .045. Simple effects analyses indicated that for both the left hemisphere and the right hemisphere there were age group differences for the sad emotion. Specifically, over the LH the middle childhood group processed the emotion of sad significantly different to late childhood children and adults, M (SE) = -.281 (.059) versus -.055 (.063), *p* =.030 and -.281 (.059) versus .049 (.070), *p* = .001. Over the RH the difference between groups was significant only between middle childhood children and adults, M (SE) = -.336 (.060) versus .060 (.071), *p* <. 001.

Pairwise comparisons, Bonferroni corrected, also indicated that there were significant differences between sad and neutral facial expressions and between sad and happy facial expressions only in the two children groups (see figure 3.9, b and c). There were no significant difference between happy and neutral faces, *F* values < 1.613, *p* = 0.211.

In the older group of children, significant differences between emotions happy versus sad and sad versus neutral were observed only on amplitudes in the RH, M (SE) = .151(.057) versus -.0130(.065), *p* < .001 and -.130(.065) versus .161(.066), *p* = .003, respectively and not at all over the midline or LH electrodes, *p* values >.091 (Figure 3.9 c).

In the adult group there were no differences between the emotions.

Summary of the standard face electrophysiology results:

Early in the epoch the distribution of the evoked responses to the faces differed across the three groups, with a marked difference between the midline and lateral electrodes. Midway through the epoch (120-180ms) it was observed a continuation of these differences in distribution, with the adults showing more marked positive amplitudes over the midline relative to the lateral electrodes. In the final period of the epoch (180-400ms) the recorded amplitudes were sensitive to the emotional content of the standard faces presented. That is, the amplitudes distinguished happy standard faces from the sad standard faces and sad standard faces from neutral, but did not distinguish happy faces from neutral. In the middle childhood children this effect was evenly distributed across the three lateral electrode locations, while in the late childhood children these were restricted to the right hemisphere, and in the adults there was no significant effect of emotion at any electrode location.

Chimeric faces trials:

Early temporal window (80-120ms)

Grand averages over the six electrode sites for each group and all chimeric faces condition are presented in figures below: happy chimeras: figure 3.10 (5-8 years group,), figure 3.11 (9-13 years group) and figure 3.12 (adults). Sad chimeras: figure 3.13 (5-8 years group,), figure 3.14 (9-13 years group) and figure 3.15 (adults)

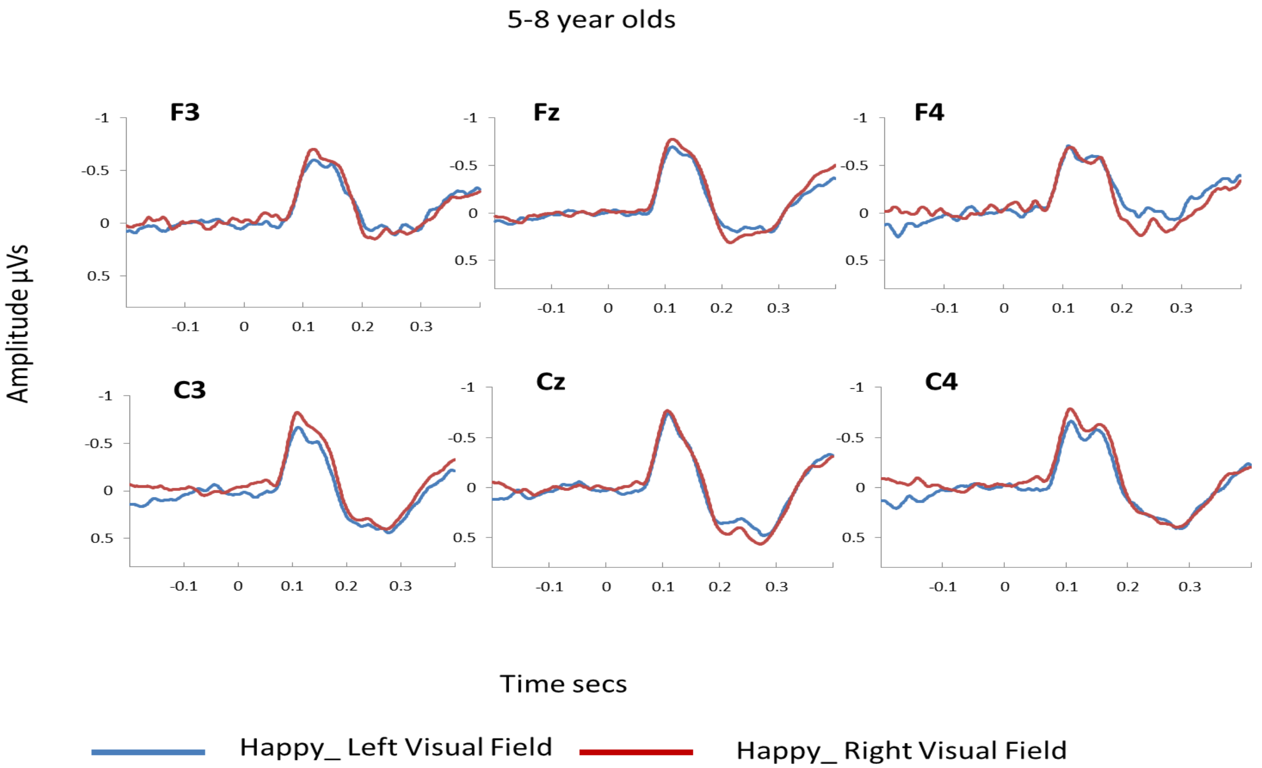

Figure 3. 10. Grand averages for happy chimeric faces conditions (LVF-RVF) for the middle childhood (5-8) group.

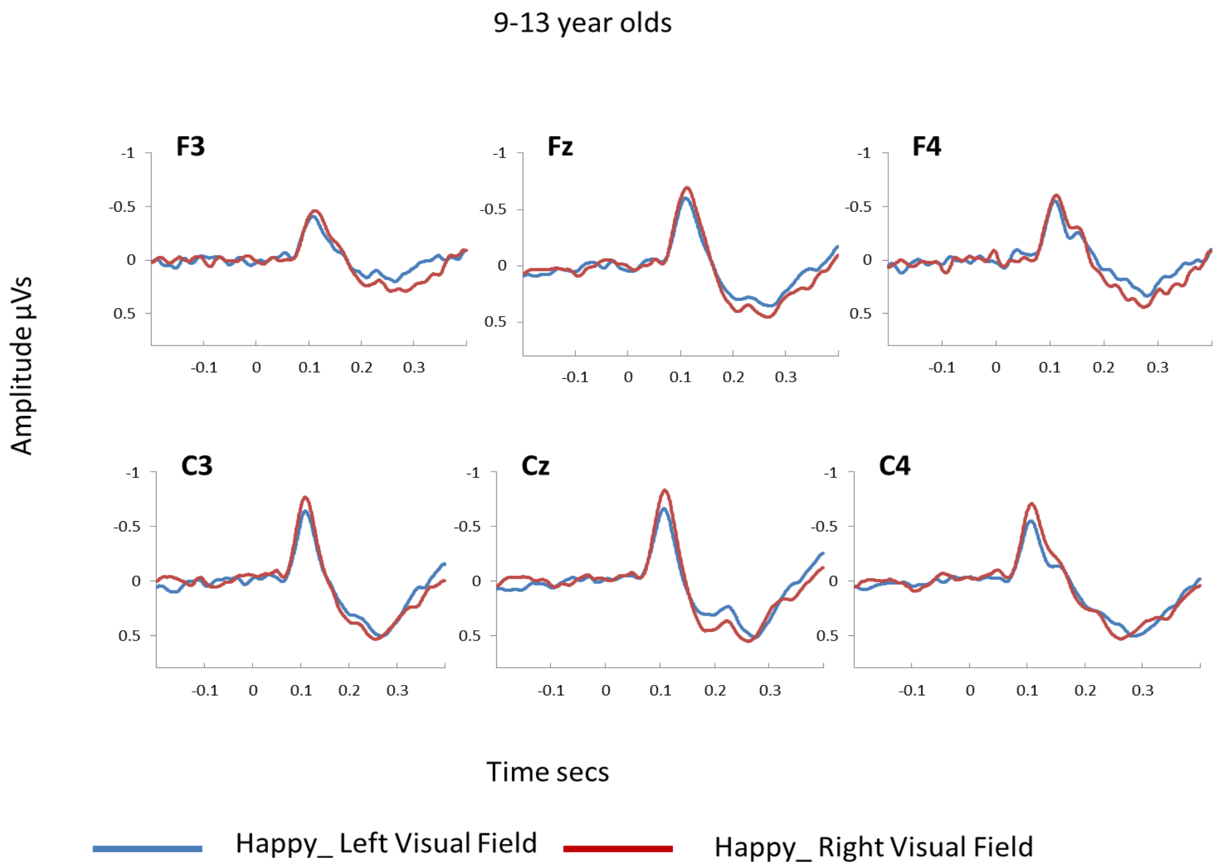

Figure 3. 11. Grand averages for happy chimeric faces conditions (LVF-RVF) for the late childhood (9-13) group

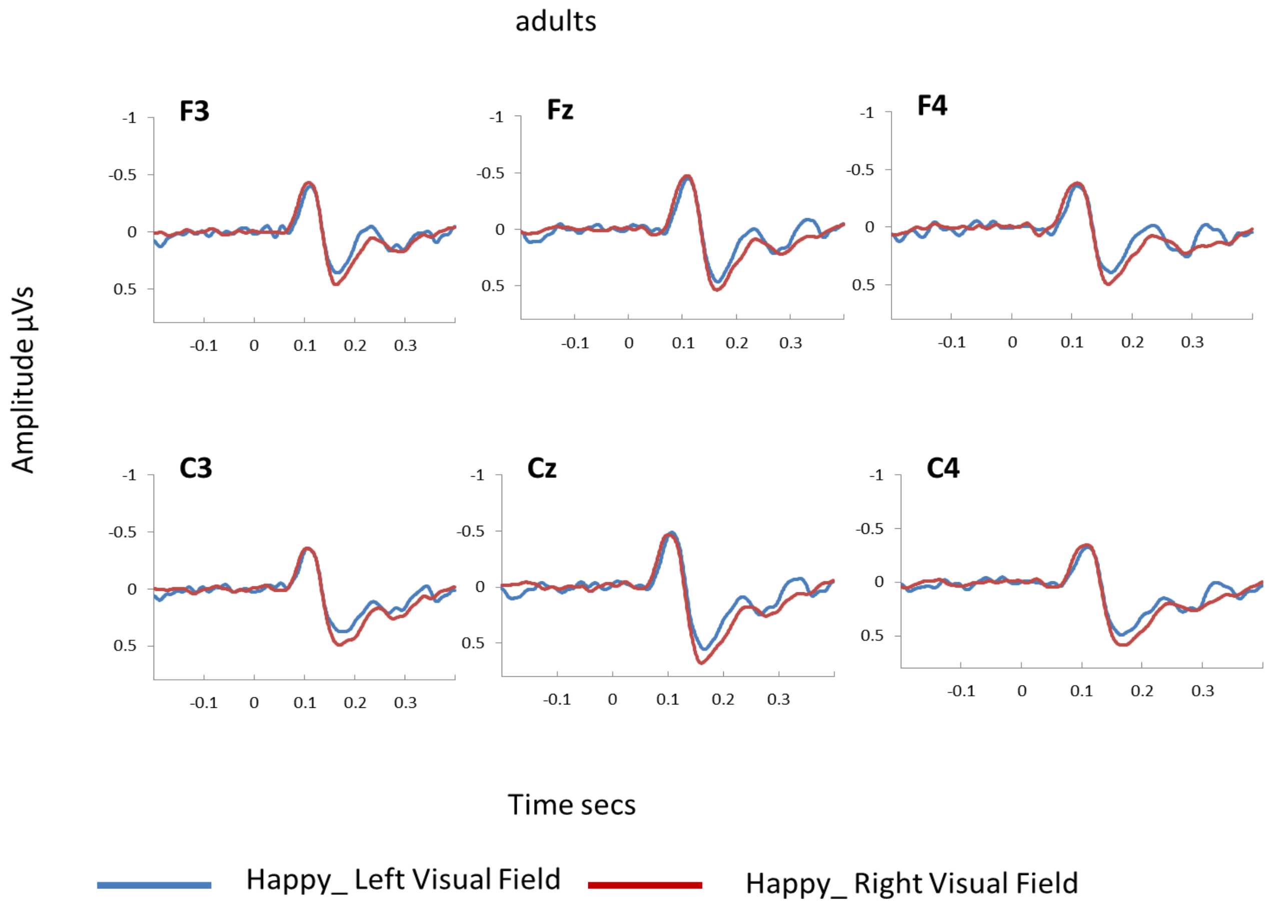

Figure 3. 12. Grand averages for happy chimeric faces conditions (LVF-RVF) for the adult group.

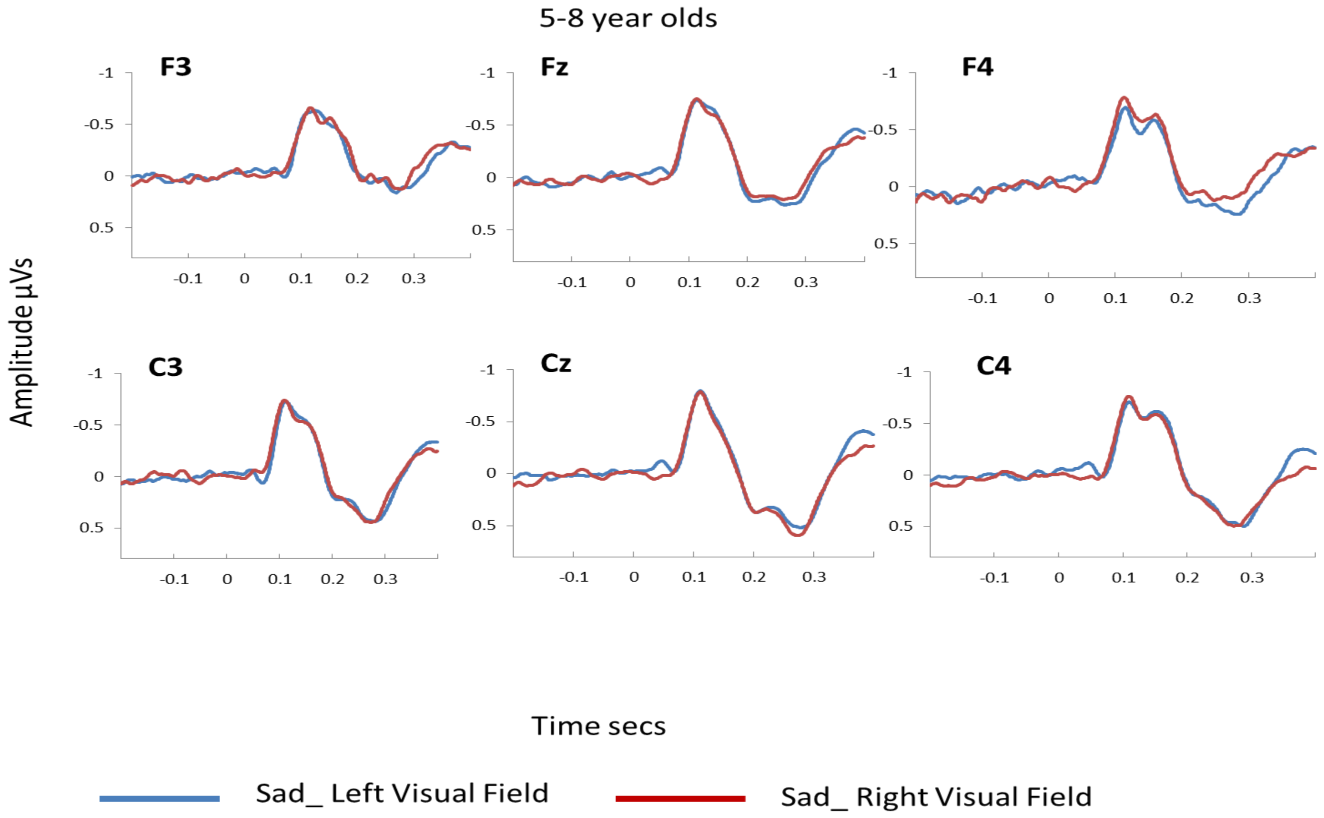

Figure 3. 13. Grand averages for happy chimeric faces conditions (LVF-RVF) for the middle childhood (5-8) group

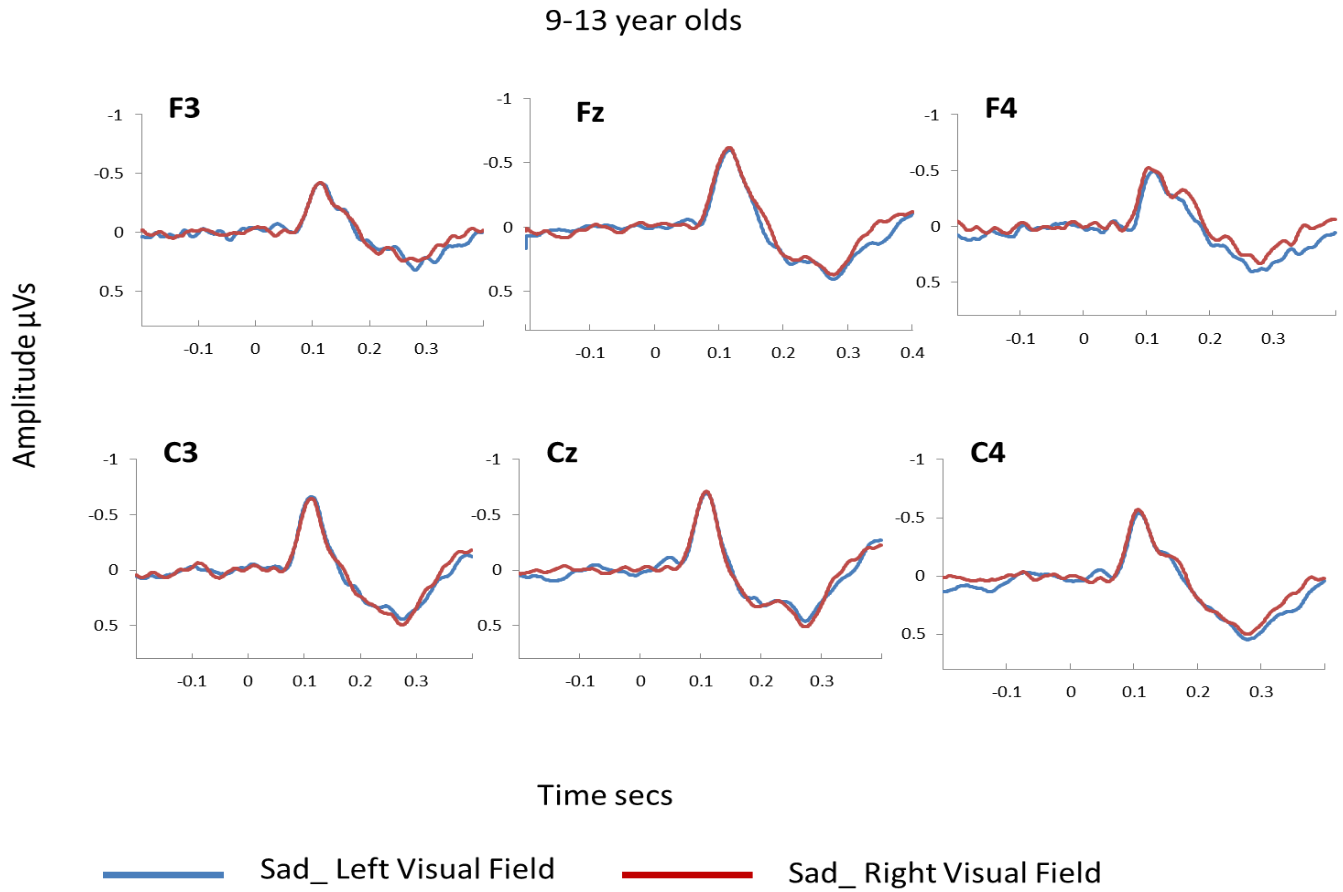

Figure 3. 14. Grand averages for sad chimeric faces conditions (LVF-RVF) for the late childhood (9-13) group.

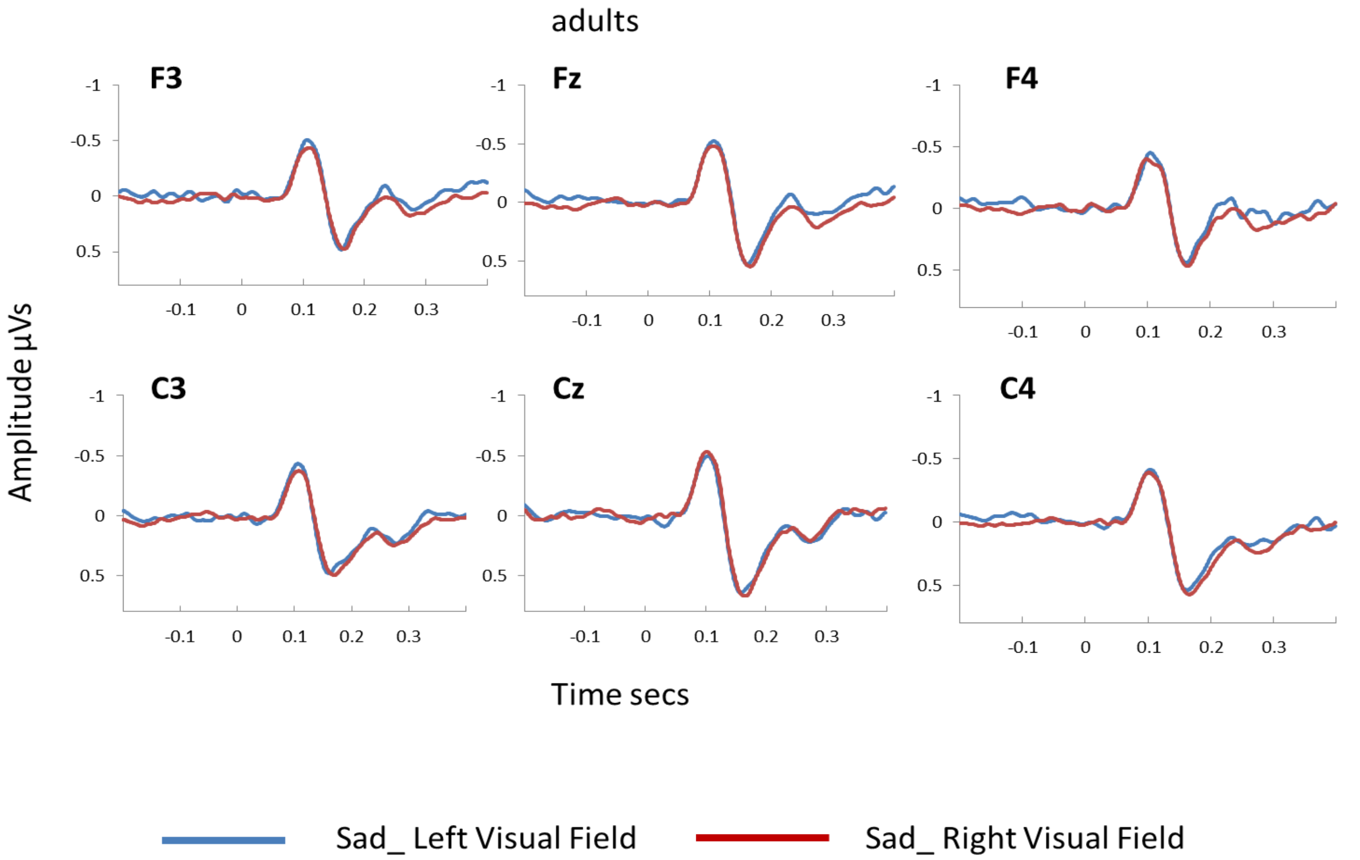

Figure 3. 15. Grand averages for sad chimeric faces conditions (LVF-RVF) for the adult group.

In the time window most closely resembling the N1 effect, we observed a significant interaction between age group and hemisphere, *F* (2,110) = 9.091, *p* = .006, η^2= .088 which was qualified by an interaction between age group, hemisphere and both of the electrode sites, *F* (2, 110) = 4.902, *p*=. 009, η^2= .082. This was because the interaction between age group and hemisphere was significant over the frontal electrodes *F* (2, 110) =6.757, *p*=.002, η^2= .109, and was not significant over the central electrodes, *F* (2,110) =2.032, *p*=.136, η^2= .036. This interaction for frontal electrodes resulted from the three age groups having significantly different amplitudes across the two hemispheres, shown by pairwise comparisons, with Bonferroni corrections: the middle childhood children's group showed a significantly more negative N1 effect in the right, relative to the left hemisphere, M(SE) =-.508 (.049) versus -.374 (.045), *p* < .001, respectively; likewise, the older children showed a significantly more negative N1 effect in the right, relative to the left hemisphere, M(SE) = -.579 (.053) versus -.517 (.049), *p* =.039. No significant difference was observed between the left and right hemispheres in the adults group (Figure 3.16).

We also found an interaction between visual field x electrode x hemisphere that approached significance, *F* (1,110) =3.785, *p*=.054, η^2= .033. The interaction resulted from the two-way interaction between visual field and hemisphere being significant over the frontal electrodes, *F* (1,110) =4.802, *p*=.031, η^2= .042. This was because there were differences in the amplitudes over the right-hemisphere dependent on the visual field presentation of the emotional content, *F* (1,110) =3.757, *p* = 0.055, η^2=0.033, whereas those in the left-hemisphere were not affected, *F* (1,110) =0.119, *p*=0.731, η^2=0.001.

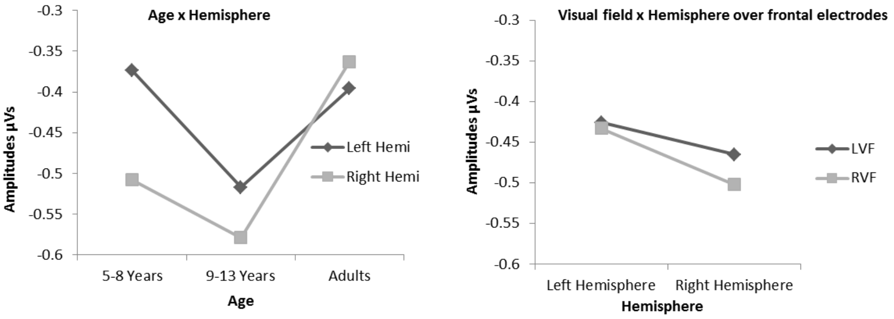

Figure 3. 16. N1: a) Age group x hemisphere and b) hemisphere x visual field interactions over frontal electrodes.

Middle window (130-180ms), VPP:

In the time window most closely resembling the VPP effect, we observed a main effect of emotion, *F* (1,110) =8.203, *p*=0.005, η^2=.069. Happy chimeras elicited more positive amplitudes than the sad chimeras, M = (SE) = .002(.034) versus -.048(.037).There was also a significant interaction between visual field and age group, *F* (2,110) =3.377, *p*=.038, η^2 = .058. This was because the difference between the two visual fields was marginally significant only within the late childhood group: M (SE) = LVF, -.196(.061) versus RVF, -.114(.060). Within the middle childhood group and adults there was no difference (p values >.478).

Late window (180-400ms):

In the time window most closely resembling the P300 effect, it was observed a main effect of emotion which approached significance, F (1,110) =3.744, p=. 056, η^2=. 033. Furthermore, a significant emotion x electrode location x hemisphere site x age group interaction was observed, F (2,110) =5.837, p=. 004, η^2=. 096. To investigate this 4-way interaction further, the analysis was run for the frontal and central electrodes separately. Over the central electrode sites, the emotion x hemisphere x age group interaction was significant, F (2,110) =5.459, p=. 005, η^2=. 084, while over the frontal electrodes this same 3-way interaction was only marginally significant, F (2,110) =2.886, p=0.060, η^2=. 046. The 3-way interaction over the central electrodes was further broken down by age group; there was a significant interaction between hemisphere and emotion for the middle childhood group (younger children) and for the adults, F (1, 43) = 5.708, p =. 021, η^2=. 117 and F (1, 30) = 16.117, $p < .001$, $\eta^2 = .348$, respectively, but not for the late childhood group (older children), F (1, 37) =0.487, p=0.567, η^2=. 008. Importantly, it was shown that for the middle childhood (younger children) and adults, the emotion of chimera (happy versus sad) affected the amplitudes over the left and right hemispheres differently. Specifically, for the adults the emotional content of the chimera (happy versus sad) had an effect on amplitudes over the RH, *F* (1, 30) = 9.524, p = .004, η^2 = 0.241, with happy chimera eliciting greater amplitudes than sad chimera. M = (SE) = .090(.065) versus .013(.063). (see figure 3.17a). However, for the middle childhood group (young children) the effect of emotion was greatest on amplitudes in the LH, although it only approached significance, *F* (1, 43) = 3.282, *p* = .077, η^2 = .044. Happy chimera elicited greater amplitudes than sad chimera, M = (SE) = .104(.048) versus .079(.054), see figure 3.17b.

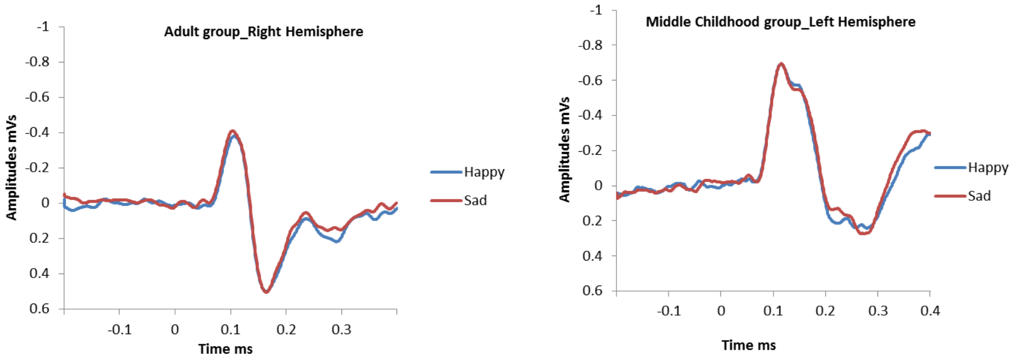

Figure 3. 17. Grand Averages showing the effect of emotion of the chimera (Happy versus Sad) on the hemispheres in a) adult group and. b) the middle childhood group (5-8 years)

Summary of the Chimeric Faces electrophysiology Results:

As with the standard face stimuli, we saw a group difference in the distribution of the early response to the chimeric faces across the age groups; the middle and late childhood children showed greater N1 potentials on the right relative to the left hemisphere, whereas the adults did not show any differences between the hemispheres. With the chimeric faces we also observed that this early response was sensitive to which visual field contained the emotional content; amplitudes in the right hemisphere were modified by whether the emotional content was in the left or right visual field, but this was not the case for left hemisphere amplitudes. It is important to note that this early effect did not differentiate which emotion was presented in the chimeric face. In the middle temporal window (120 to 180ms), we observed emotion differences with the chimeric faces; happy chimeras elicited greater amplitudes than sad chimeras. In the final period of the epoch (180-400ms) the amplitudes that we recorded were sensitive to the emotional content of the standard faces presented. That is, the amplitudes distinguished happy standard faces from the neutral standard faces and sad standard faces from happy, but did not distinguish sad faces from neutral. With the chimeric faces, this differentiation between happy and sad chimeras was strong over the LH for the young children and over the RH for adults.

3.2.3 Discussion

The main purpose of this study was to explore age differences in the observed ERP responses to emotional faces and whether older age groups show more lateralisation for processing facial expressions of emotion than younger age groups. A secondary aim of this study was to explore the neural markers of early facial emotion processing over frontocentral sites, and whether activation differed for these sites with age. For the chimeric faces part of the study the main aim was to find evidence of contralateral effect of visual fields of emotion presentation. The three measurable electrophysiological events over frontocentral sites were: a N1 showing a large negativity at about 100ms poststimulus, a VPP, a positive potential between 130-180ms, and a positive wave between 180-400ms, the P300.

This research has provided preliminary evidence that these three components undergo developmental changes during early processing of standard facial expressions. As expected, early in the processing marked amplitudes differences were seen between the 5-8 year olds and adults, with amplitudes decreasing with increasing age. Interestingly, in this study shifts of hemispheric asymmetry were observed especially in the two children groups in the processing of standard faces. A bilateral processing indicated by greater activation over the midline electrodes at the beginning of the processing developed into a RH advantage for the older children for the differentiation of the three emotions in the late window. Most importantly, this research found a contralateral effect of visual field presentation of the emotion in chimeric faces viewing which differed between younger children and adults. These findings are discussed in more detail below;

First the standard faces data set is being discussed: general age effects are discussed, followed by the effects of emotions on the ERPs, and finally laterality effects for the standard face stimuli.

Standard faces

Age effects

N1

N1 decreased significantly with increasing age. The difference was present between all three age groups but it was significant between the younger children and the adults and for each of the two emotional and neutral expressions. This finding is consistent with previous research (Batty & Taylor, 2002,2006) which has suggested that this decrease in amplitude is an “effect of maturation”, (p. 486) and indicates a progressive decrease in cortical activation, perhaps by increased automatisation in emotional processing with age (possibly due to continuing maturation and increased myelination of the neural pathways). The effects of maturation on this early ERP, according to Batty and Taylor (2002), starts before 7 years of age and continued during childhood; specifically, it is seen to start in the middle childhood group (5 to 8 year olds) in this study.

VPP

Activation of the VPP was evident only in the adult group. This was an expected finding and supports previous findings on the VPP (Botzel, et al, 1995; Itier and Taylor, 2002). As explained in chapter 2, VPP (Vertex Positive Potential) is the positive frontocentral counterpart of the N170, a negative occipito-temporal component at around 170ms whose amplitude is larger in response to faces than to other objects. Our data reflects the development of this component described in the literature. Researchers have reported that the VPP starts to be formed as a positive ERP in later childhood group and reaches the same looking positive wave reported by previous studies in adulthood. Whilst the N170 appears very early (6months), its counterpart, the VPP cannot be recorded in children until the age of 12 (Taylor et al., 1999). The absence of the VPP in young children is thought to be due to modification of cortex folding, and thus dipole orientation, with development rather than the sudden appearance of a new dipolar source (Joyce and Rossion 2005).

P300

Age effects were found also in the late time window P300 as the amplitude of P300 showed decreased negativity with increasing age. In fact this late activity was negative in children and positive in adults. This indicates quantitative age differences in emotion processing. However, significant differences between the younger group and adults were found only for the processing of sad faces over all three laterality levels. In other words, this study found that the youngest children seem to process sad expressions of emotion differently than adults thereby demonstrating age related differences of sad processing. The sad emotion appeared to invoke greater frontal processing negativity, suggesting increased processing requirements. This finding of an age related effect over the frontocentral sites is consistent with previous research (Batty and Taylor, 2006) which has also found a decrease of negativity with increasing age in the late window between 300 and 400ms. Both findings are in line with the maturation hypothesis suggested by Batty and Talylor (2002), whereby the number of synapses decreases after the age of 8 years. This underlying neuroanatomical maturation might cause the amplitude decrease with age.

The finding of quantitative age differences shows that something interesting is happening to sad processing with age. These differences in processing of sad emotion between younger children and adults may indicate slow development of sad processing before establishing adult levels of activation. While our findings are not consistent with Batty and Taylor (2006) who found no age effects of emotion processing in children from 4 to 13 year olds over frontocentral sites, they may enlighten contradictions found in behavioural studies regarding the development of sad expression recognition. Behavioural research (reported in chapter 1) considered the ages at which different emotions are processed efficiently at an adult level: happiness is recognised accurately at a level similar to adults at 4 years of age, sadness by 5 to 6 years of age, fear at 7 years, anger at 9 years and disgust at 11 years (Herba & Phillips, 2004). For sadness, however, there is also evidence that the ability to recognise sadness does not reach adult level until the age of 10 years (De Sonneville et al., 2002; Kolb et al, 1992; see discussion in Chapter 1). This study provides physiological support for the latter. Neural processing of sad expression seems to reach adult level between 9-13 year olds. Perhaps children are able to recognise the valence of the sad emotion as early 5 years as reported (Durand et al., (2007), chapter 1), but recognition narrows to a specific emotion later in childhood. Further investigation is needed to resolve this conflict.

In summary, the frontocentral emotion processing within the 400ms window had the same pattern across the three age groups only in the early time window. There seemed to be quantitative developmental changes, indicated by decreasing amplitude with increasing age) which indicate increased automaticity and increasingly expertise recognition of facial expression with age reported by behavioural research. However, in the late window we found age differences in the processing of sadness between younger children and adults, indicating a prolonged maturation of the neural processes of sadness as opposed to happiness.

Emotion effects

N1 and VPP

Contrary to our expectations, the N1 and VPP amplitudes did not appear to be modulated by emotional expression as they did not vary significantly between happy, sad, and neutral expressions in any of the three age groups. This finding contradicts our finding in the previous study reported in this chapter, and a number of studies which investigate early processing of facial expression in adults. Our finding, however, is consistent with a small number of studies which suggested that the emotional content of the facial expressions does not modulate these early ERPs within the 100ms poststimulus. Very few (in fact, two) developmental studies on emotion recognition with 7 and 10-16 year old individuals, and one with single neuron recordings in macaque monkeys are consistent with our null finding; these reported studies found no modulations of the amplitudes of the early N1 by neutral, happy, and fear emotions (Leppanen et al., 2007; Sugase et al., 1999; Wong, et al., 2009). The work by Sugase et al. (1999) using single cell recordings in macaque monkeys’ temporal cortex while they observed monkey and human faces with different expressions supports the idea that early components may demonstrate coarse categorization of visual stimuli (face/non-face), whilst within category detailed discrimination between different emotions emerges at later stages of emotional processing.

Batty and Taylor (2006) is the only study to our knowledge that examined temporal processing of emotion in a wide range of children (4-15 year olds) using an implicit emotion task (children responded to non-facial stimuli) and using all six basic emotions and neutral expressions and therefore we can compare their findings with ours. They found emotion effects on P1 latency (so the timing of the peak and not the amplitude) which distinguished the negative emotions from positive/neutral emotions and on N170 (VPP is its dipolar frontocentral counterpart, chapter 2) only in the 14-15 year olds group. As the primary interest of this work was in the effects of laterality, latency information was not assessed.

Importantly, when considering the findings of this study there is a possible explanation for example why there were no hemispheric processing differences as were found in previous work: it is possible that the nature of the task used in this research played a role. In this study the task was an implicit emotion processing task, rather than an explicit emotion processing task, as participants passively viewed the stimuli (asked to respond to the changing fixation point rather than respond to the emotional content of the stimuli). Mangun (1995) showed that N1 is an attention sensitive component. Visual selective attention improves perception and also modifies sensory inputs at an early stage of processing prior to higher stages of perceptual analysis. In support of this, Holmes et al. (2003) showed greater amplitudes in response to attended fearful faces as early as 100ms, as opposed to unattended fearful stimuli where the emotion effect was completely eliminated.

A second possible explanation for the present finding concerns the emotions used (happy, sad, neutral). Many of the aforementioned studies with adults who did find emotion effects on N1 and N170 indeed used highly arousing emotions (anger and fear). This has been specifically reported by Batty and Taylor (2003) and Rossignol et al. (2005) who both reported that fearful and angry (highly arousing) facial expressions elicited larger N170 amplitudes than happy and neutral expressions. In fact, Kawasaki et al. (2001) showed that single neuron responses to emotional stimuli in frontal cortex (scenes and faces) are influenced by the emotional content of the stimuli as early as 120-160ms after stimulus onset. However, they reported that the firing rate to aversive stimuli (fearful facial expressions) was significantly greater than to happy and neutral expressions. No significant difference was found between the pleasant and neutral stimuli in such early latency. Perhaps in this study there was not an early effect of emotion on N1 or VPP for adults due to the sad expression not being as highly arousing an emotion.

P300

The present study found a frontocentral main effect of emotion. The three emotional expressions elicited different amplitudes after 200ms. Sad expressions had significantly different amplitudes than happy and neutral expressions. These findings are in line with previous studies regarding reported significant differences in the processing of angry/fearful facial expressions relevant to happy/neutral ones from 200ms. For instance greater frontocentral positivity for fearful faces has been reported by Eimer and Holmes (2007) starting at about 230ms, right through to 1000ms. Schupp et al. (2004) also reported an EPN (early posterior negativity) with corresponding central-medial positivity from 200ms which was significantly modulated by emotion, with threatening faces eliciting higher amplitudes than neutral and friendly faces. Furthermore, Marinkovic and Halgren (1998) found a negativity at 240ms to be more negative for emotional expressions than neutral ones over occipito-temporal sites. Other studies also support the same emotion modulation of a P300 component at occipital-parietal sites (Vandeerploeg, et al., 1987; Kestenbaum, et al., 1992; Laurian, et al., 1991).

Carretie, et al. (1996) convincingly showed that the P300 amplitude increase in occipito-parietal sites found in the aforementioned studies occur in response to stimuli that are task relevant. Therefore, they concluded that the emotional stimuli might have elicited greater P300 not because of their emotion content, but rather because of their relevance to the task performed (explicit emotion task). Specifically, Carretie and colleagues showed that the N300, a negative component at parietal sites, is a more suitable component for discrimination of different emotional visual stimuli, and is less influenced by cognitive variables than P300. The component observed in the present study over the frontocentral sites seems to be the positive counterpart of

N300 and appears to be modulated by emotion at this time window, but what drives this modulation is the sad expression.

The sad faces seem to be processed differently than happy and neutral ones. Previous studies have reported differential processing of fear and threatening stimuli, compared with neutral or friendly faces, which started early and prior to detailed perceptual processing encoding, and persisted throughout the 450ms window (Schupp, et al., 2004; Williams, et al., 2006). This different pattern of fear processing might indicate that elaboration of fear/threat related stimuli may be mostly separable from the processing of neutral and positive emotions, and that signals of threat might serve to enhance continuous stimulus elaboration and context evaluation. Williams et al. (2006) reported that the sources of this differential processing suggested the involvement of distributed and interacting networks over the time course of emotion processing.

The above findings are analogous to present findings in the differential processing of sadness compared to happy and neutral expressions. Blair et al. (1999) showed that the neural response to sad facial expressions mirrors that to fearful expressions, as they both activate the amygdala. Therefore one can look at the amygdala as a possible explanation of such ERP differences between emotions. The modulation of cortical activity by the amygdala, however, is indirect. Whilst it is unlikely that the cortex recorded ERPs reflect amygdala activity directly, because of the closed-field organization of neurons in the amygdalae and its deep position with respect to scalp surfaces, there are anatomical connections between amygdala and sensory representation areas in the ventral visual pathway. Amygdala directly projects to sensory cortices, providing an effective mechanism to enhance processing of emotions, modulate and enhance cortical processing, guiding processing resources to emotionally significant stimuli (Vuilleumier, 2005; Williams et al., 2006). However, an alternative explanation could be considered for the difference in sadness, happy/neutral processing. Sad expressions are ambiguous, and are therefore more difficult to recognise than happy and neutral expressions.

Laterality effects

The current study found a bilateral processing of the 3 facial expressions from 100ms to 180ms for N1 potentials. It was found that the amplitudes of N1 were significantly higher over the midline sites for all expressions (happy, sad and neutral) and for the three groups. No difference was found between the left and right hemispheres in all groups. The bilateral processing was shifted for the P300 component but only for the sad emotion and only for the older children and adults. The amplitudes of P300 to sad emotion were significantly different than happy and neutral over the Right Hemisphere (RH). The difference for the younger group remained across all three laterality levels (left, right and midline). This study shows that whilst children and adults are bilateral very early in the processing of facial expressions, they develop an RH advantage for processing of sad from the age of 8-13 years which does not differ from of adults. This finding is important in the context of behavioural studies with children reviewed in chapter 1 which show a development of laterality between the ages of 5 and 10. More specifically, the present study supports the findings of]=]]= Workman et al. (2006) showing that whilst recognition of happiness is right lateralised from an early age (5-6 years), laterality of sad was marginally different between 5 and 10 year olds. It is important, therefore, that this is the first study to validate a behavioural finding with physiological measures. It would be interesting to see whether responses to other facial expressions support the behavioural findings reported by Workman et al. in further investigation.

As far as the pattern of laterality found within the 80-120 and 180-400ms time windows of emotion processing, it is also interesting as it shows a flux of the hemispheric asymmetry. More specifically, a bilateral processing for all, it remained bilateral for the younger children and it became RH advantage for the older children group and adults. This pattern of laterality changes partly contradicts one electrophysiological study with adults as far as the early window laterality is concerned. Vanderploeg et al. (1987) showed that the distinction between emotional and neutral facial expression is a categorical decision made earlier and in the LH, whereas the continuous processing of the specific emotions employs the greater facial expression recognition ability of the RH. For the late window, however, our study supports the findings of previous studies about RH advantage later in the processing. Marinkovic and Halgren (1998) and Vandeerploeg et al. (1987), for instance, reported greater amplitude for the emotional facial expressions (positive or negative) than for neutral over the RH at a later time window (450- 600ms). Whilst both the above studies are methodologically different to the present study (they used explicit tasks where participants were asked to rate emotional faces), they point to the direction of, first, a laterality shift towards later components of emotion processing and second, a differentiation of the processing between different facial expressions. Laterality effects (RH advantages) were also found by Kestenbaum et al. (1992) and Laurian et al. (1991), at latencies ~300ms.

Another direction of explanation for the different pattern of asymmetry between the two time windows is a subcortical structure such as the corpus callosum (CC), and its development. Research in the development of CC as seen in chapter 1 showed structural changes, increase of the posterior part of the CC, over development and, therefore, interhemispheric interaction continues to improve during childhood and adolescence. Additionally, it is known that as myelin continues to increase, until late teen years, in size around callosal neurons the speed of information interchange increases with age and so does the laterality (Hagelthorn et al., 2000). Until then the hemispheres of young children are more functionally disconnected than those of adults. Children do not exhibit the same advantages of dividing processing across the hemispheres as observed in adults (Banich, 1998; Giedd et al., 1999).

More specific to emotion processing, Compton et al. (2005) found that the emotional information of faces facilitate the interhemispheric communication in adults in an implicit task. Kinsbourne (1982) put forward the idea that CC is rather concerned with an excitation – inhibition balance between hemispheres. Thus, depending upon task demands, the CC will either "concentrate activation" of one hemisphere or distribute activation between the two hemispheres. Without such equilibration attention will swing from one hemisphere to the other. This perhaps explains the bilaterality observed in all participants in the present study at the beginning of processing. This study shows that this equilibrium is present in children as young as 5 years old.

At 200-400ms a RH advantage was observed for all three facial expressions, but the advantage became significant for the sad expressions, not for happy. The present study further illuminates the finding by Schupp et al. (2004) and Williams et al. (2006) that sad facial expressions of emotion are processed differently throughout the 450ms window, insofar as the asymmetry of the processing is concerned. The RH takes over at 200-400 ms and differentially processes the sad and neutral expressions, but not the happy. This finding could be explained by the fact that sad expressions are very similar in facial configuration to neutral (Etcoff & Magee, 1992) and therefore more ambiguous and more difficult to recognise, whereas the happy expression is automatically recognised at very early age.

Chimeric faces

The focus in the analysis of the chimeric faces task was to find laterality trends, hence the interactions between side of presentation of emotion and hemisphere. It was expected that in adults, the ERP amplitudes to the chimeras with the emotion on the left visual field (LVF) would be of greater amplitude over the right hemisphere (RH) whilst the responses to the chimeras with the emotion on the right visual field (RVF) would be greater over the left hemisphere (LH). Furthermore it would be anticipated that if that the right hemisphere is more specialised for emotion processing we would see greater ERP amplitude in general for LVF than RVF presentation (recognition of emotional content). It was also expected to find a developmental change in the asymmetry expected.

In the early window, the N1 amplitudes in the two hemispheres were not affected by the visual field of emotion presentation over frontal electrodes. It was not until the 180-400ms that we saw some contralateral effect of visual field presentation on the hemispheres in the middle childhood (younger) children and adults, but only for the happy chimeras. For the happy chimeras for the middle childhood age group when the emotion was shown in the right visual field greater amplitudes compared to the sad chimeras were seen over the LH. The different pattern was observed in the adults group: happy chimeras elicited significantly greater amplitudes than sad over the RH when the emotion was shown in the left visual field.

This finding partly supports Killgore et al. (2007) who found that is an fMRI study that with left visual field emotion presentation the RH was more activated than the LH for both happy and sad chimeras, and for right visual field emotion presentation the LH was more active than the RH with both happy and sad chimeras.

It was not found, as anticipated, greater ERP amplitude in general for LVF than RVF presentation (recognition of emotional content). One possible explanation is that with LVF presentation the processing is more automatic, therefore the amplitudes smaller. With RVF presentation increased amplitudes might indicate the harder processing demands by the interhemispheric transfer of the emotional information from the receiver left hemisphere to the right hemisphere.

In summary, this study provides additional if limited evidence that the emotive chimeras do produce differing patterns of processing in the brain, and therefore lend support to these stimuli being used within tests of laterality (Levy et al., 1983). Secondly, this study demonstrates that there are some developmental differences in the laterality bias observed, with children in middle childhood and late childhood having different processing patterns for happy chimeras than adults. Perhaps the strength of lateralisation differences reported in the literature might account for the pattern we observed in this study. In fact, findings show that individuals become RH lateralised for processing of happy facial expressions of emotion earlier than for negative facial expressions of emotion. Why the findings were only for the happy chimeras requires further investigation, but this will be discussed a bit further below.

3.3 Conclusions

Through the two studies presented in this chapter it was shown that both children and adults have lateralisation for emotion processing, and that for some components this lateralisation differs depending on the age of the individual and the emotion being viewed. Importantly, both the viewing of full facial images showing expressions of emotion and the viewing of the chimeric faces produced these lateralised effects of emotion processing in the brain. Specifically, the neural correlates when viewing emotive chimeric faces, both when used in the explicit and implicit emotion processing tasks showed patterns of electrophysiological responses of early emotional processing at the frontocentral sites.

Before exploring the main question of laterality, it was important that in Study 2 the developmental pattern observed in electrophysiological responses to early emotional processing at frontocentral sites was consistent with previous research. The activity pattern was similar across the three age group; although amplitudes were lower with the older age groups than the younger age group. This finding supports the increasing automatisation of processing and recognition of facial expressions. Additionally, it was shown that there was differential processing of the sad emotion, but that this was observed only between middle and late childhood. As discussed in chapter 1, that the age when the recognition of sad reaches the adult level is debated in the literature. This finding complements behavioural studies which suggested that the sad expression is recognised at the level of adults by the age of 10 years (De Sonneville et al., 2002; Kolb et al, 1992; Chapter 1).

With regard to laterality, this set of studies showed that the neural activity when participants completed the CFT reflected the crossed asymmetry reported by behavioural studies of laterality whereby the emotion depicted in one visual field was perceived and processed by the contralateral hemisphere. This was a significant effect only for participants who had a left visual field bias (RH). The interesting finding we observed was the unfolding of this effect during the 400ms time window. More specifically it started very early in the processing, from 100ms, as a general crossed effect (the RH laterality group had significantly greater activity over the RH) and, at 180ms, became specific to visual field of emotion presentation (when RH laterality group saw the sad emotion on their LVF had greater activity over the RH). Therefore, we can safely say that first, the behavioural findings of the CFT are mapped onto the neural processing of emotions and second that something interesting is going on in the RH from very early on in the processing.

A second interesting finding which will enrich our understanding of the CFT is the fact that only the explicit emotion processing task (Study 1) elicited the crossed effect of laterality and not the implicit emotion processing task (Study 2). This highlights the possible effect of attention to emotion processing. There are different processes involved in implicit versus explicit emotion processing (section 2.3.4). A fair amount of research shows that emotions from faces are processed preattentively, rapidly and in parallel with other aspects of initial processing of visual stimuli, even when the emotional content of faces is not explicitly judged by the participants (Pizzagalli et al., 1999, 2002). Other studies, however, have shown that automatic allocation of attention gives priority to high arousal facial expressions (Anderson, 2005; Kawasaki et al., 2005) and others that the early emotional processes are gated by spatial attention (Eimer, Holmes & MacGlone, 2003). Our finding for the effects of laterality on the viewing of the chimeric faces reflects the differential cortical processing between explicit and implicit emotion processing. It is known that the CFT asks participants to judge which face is more emotive, a very explicit task of emotion processing (direction of attention to the emotive information of the face), therefore, it would be expected that similar processing as that occurring in Study 1 would be occurring in the brain when participants complete the CFT.

It is interesting that the finding of study 1 was not found with the chimeras in Study 2. This could be because of their lack of ecological validity, as we do not see emotional chimeric faces in our everyday life and when free viewing, without attention directed to the emotionality of the stimuli, it is possible that more facial and featural information is being processed in the early stages rather than emotive information. Another possibility, which is in line with the evolutionary perspective of emotion processing, is that implicit emotional processing requires subcortical structures that EEG does not have access to (especially the amygdala). This is supported by the fMRI study by Killgore and Yurgelun-Todd (2007) who found with an fMRI study the contralateral effect of visual field of emotion presentation on subcortical structures.

Attention allocation to the emotion of a face or not can probably explain the difference observed in the emotion modulation on the ERPs in the two tasks where emotion modulated N1, VPP and P300 but this was not seen in the implicit emotion recognition task.

Interesting was also the laterality pattern observed in the processing of the standard faces during the initial 400ms of processing. Study 2 showed a flux of the hemispheric asymmetry. More specifically, an initial bilateral advantage for all, children and adults, remained bilateral in middle childhood and it became a RH advantage in late childhood group and adults. Whilst this finding shows a trend towards RH processing for late childhood and adults (in line with the literature), it would be interesting to see whether bilaterality in middle childhood children would shift to RH for happy processing (suggested by literature) at a later latency , beyond the 400ms time window. Another interesting finding is that this RH shift of asymmetry was observed during the late time window where differentiation of the three emotions also took place.

In summary, this study has shown that there is laterality for emotion processing of facial emotion with both full face and chimeric faces, and that the processing differs at different ages. Through this discussion it was seen that sad faces show differential processing due to age related trends in emotion recognition ability. In the next chapter emotion processing will be explored in terms of how it may predict emotion recognition ability.

Chapter 4: Linking hemispheric processing of emotions to children's emotion recognition skills

In the previous chapter we explored the patterns of electrophysiological responses to early processing of facial expressions of emotion at frontocentral sites. We found different distributions of the responses to viewing standard (full) faces across three age groups (two groups of children and one group of adults), with the amplitude (activation) decreasing with increasing age. We also found lateralisation patterns changing between the younger children and older children and adults in the processing of chimeric faces, with a LH advantage in younger children shifting to the RH advantage for older children and adults. Most importantly, with the chimeric faces we observed differential processing depending on which visual field contained the emotional content. This was more prominent in the right hemisphere where processing was modulated by whether the emotional half of the stimulus was projected to the left or right hemisphere showing physiologically that the CFT is a test of laterality from very early in the processing. However, this tells us little about how the processing of facial expressions of emotions is linked to children's performance on recognition tasks of facial expressions of emotion.

The primary goal of this thesis is to identify whether developmental changes in the processing of facial expressions of emotion in the brain may predict developmental differences in facial emotion recognition skills across childhood (reviewed in chapter 1). To recap briefly, as discussed in Chapter 1 the ability to recognise basic emotions from faces emerges gradually with age and varies with emotion. Reichenbach and Masters, (1983) found that 4 years old were 85% accurate in identifying happiness but they were less accurate in judging sadness (62% accuracy), anger (56%) or neutral expressions (43%) but at the age of 9, children had significantly improved accuracy in the recognition of sadness. Durand et al. (2007) found that recognition of happy and sad faces reached adult-like levels at the age of 5 years, fear reached the adult accuracy level around the age of 7, anger at 9 years and disgust by 11 to 12. In fact, happiness has been consistently reported to be recognised earliest followed by anger or sadness and then surprise or fear and finally disgust. Importantly, children's accuracy on emotion recognition tasks has not been fully explained.

In addition to the development of emotion recognition, it was previously discussed that there are developmental trends in children's strength of laterality between early to middle childhood. Specifically, Levine and Levy (1983) have demonstrated that children are lateralised for happy emotion processing by age five, while Workman et al. (2006) have shown that there are different ages at which hemispheric processing for different emotions becomes more lateralised to the right hemisphere. In fact, Workman and colleagues have found with chimeric faces that happy facial expressions of emotion become right hemisphere lateralised from an early age (5-6 years), laterality of sad was marginally changed between 5 and 10 year olds, fear has a higher laterality score in the 10-11 age group, surprise and disgust at the age of 7-8 years and anger at the age of 10-11 years. To reconcile the understanding of developmental changes in emotion recognition, researchers have begun to explore links between emotion recognition skills and brain development (including hemispheric laterality for emotion processing and maturation of neural processes). It is important to investigate how emotion processing in the brain may be related to performance on emotion recognition tasks. There is very little work that explores both hemispheric processing in the brain and emotion recognition ability.

Barth and Boles (2008) presented a model regarding the link between hemispheric laterality for emotion processing and links with emotion recognition skills. In this model it was proposed that the timing of when the brain becomes lateralised for emotion recognition leads to differential relationships being found between hemispheric processing and related task performance. For instance, they believed that as the brain becomes lateralised for language processing in early childhood that links between lateralisation of processing and performance on language tasks will be positive (greater lateralised individuals would have greater performance). However, as the brain becomes lateralised for emotion processing in early to middle childhood, links with emotion task performance will be negative (more RH lateralised, the worse the performance in emotion tasks). Interestingly, more recent evidence presents a slightly different picture (e.g., Watling & Bourne, 2007; Workman et al., 2006).

As highlighted very little research has explored the direct links between emotion processing and emotion recognition. Research with adults have found that RH brain-damaged patients (RHD) patients were markedly impaired relative to left hemisphere brain-damaged patients (LHD) patients in the recognition of emotions in facial expressions (Bowers, Bauer, Coslett & Heilman,1985; DeKosky, Heilman, Bowers & Valenstein,1980; Kucharska-Pietura & David, 2003) Following from the adult research the work completed with children's hemispheric asymmetry for emotion processing and task performance has shown that children who are more strongly lateralised in their emotion processing perform better on emotion tasks. In fact, Workman et al. (2006) showed that not only does the strength of right hemisphere lateralisation increase with age, but there is a significant positive correlation between 5- to 11-year-old children's strength of right hemisphere lateralisation for emotion processing and their ability to recognize emotions expressed in a set of eyes. Additionally, children who have greater strength of right hemisphere lateralisation for emotion processing performed better on a task where they were judge what a protagonist would feel in a cartoon situation. Moreover, Watling and Bourne, (2007) found a positive relationship, emerging at the age of 10 years, between children's strength of lateralisation for processing emotions and their ability to judge that a protagonist hides their feelings for self-representation motivations. Of particular interest, all of these tasks of which researchers have found links between hemispheric emotion processing and task performance have been more complex than standard emotion recognition tasks (require a level of theory of mind, which is an understanding that others have different thoughts and emotions to the self); this therefore is more advanced and fails to address more immediate links such as that with actual emotion recognition ability. Therefore, the two research studies in this chapter explore the links between hemispheric laterality for emotion processing with children's facial emotion recognition performance.

Within this chapter, the first study (Study 3) sets out to explore longitudinally (over the period of one year) how developmental changes in facial emotion processing within the brain are related to developmental changes in facial emotion recognition performance. This will provide evidence as to whether the strength of lateralisation for processing emotions from faces can predict developmental changes in the ability to accurately recognize facial emotions.

In the second study (Study 4), the method for assessing laterality is modified to use the divided visual field paradigm (see details of this task in Chapter 2), as this is a paradigm frequently used in adult hemispheric asymmetry research. Additionally, as children in their everyday life view lower intensity facial expressions, in comparison to full intensity expressions, in the second study emotion recognition is assessed using stimuli that vary in intensity. This second study therefore assesses how laterality for emotion processing may relate to sensitivity to recognize facial expressions of emotion.

4.1 Study 3. Longitudinal implications of development of hemispheric laterality for emotion processing in children's emotion recognition ability

Researchers know that emotion recognition skills develop with age and that recognition of each emotion develops at different time points. Additionally, it is known that there are individual differences in when emotion recognition emerges and when it reaches the adult level. Along similar lines, researchers have documented that the strength of lateralisation for emotion processing develops with age and that the laterality for emotion processing of each emotion becomes lateralised at different time points. This study is designed to investigate the role of hemispheric lateralisation for emotion processing in predicting increases in children’s emotion recognition skills over a one year period.

We employ a longitudinal design in order to behaviourally assess the developmental changes of accuracy in facial emotion processing one year later, but most importantly, the main aim of the study is to explore whether the development of strength of lateralisation for processing emotions from faces predicts the development of the ability to accurately recognize facial emotions. This will contribute to greater unfolding and better understanding of children’s facial emotion recognition evidenced development and will help to explain the variation we find in behavioural performance of facial expression recognition skills.

In study 1 and 2 of this thesis (previous chapter) happy and sad chimera were used and the electrophysiological findings in these were primarily relevant to sad emotion processing, the hemispheric processing of an additional negative emotion was assessed (angry). Much of the research to date focuses on laterality for happy faces. Angry was chosen as an appropriate emotion to explore alongside sad and happy as both sad and angry hemispheric lateralisation, with right hemisphere dominance for emotion processing, are among the earliest to emerge (Workman et al., 2006).

In the present study 3 the chimeric faces test (CFT) is used to measure laterality. For emotion recognition skills three tasks were used to assess different aspects of emotion recognition: emotion matching, emotion discrimination task, and identity matching tasks. As discussed in Chapter 2, the emotion recognition tasks have been adapted from the battery of facial emotion recognition tasks for children developed by Bruce et al., (2000). As suggested by Bruce et al., the tasks in this study include trials of different aspects of emotion recognition and with varying levels of difficulty. For example, emotion discrimination tasks examine conceptual knowledge of emotion (i.e., the participant's ability to recognise an expression as belonging to the category of a specific emotion, such as happy, sad, etc.), whereas the emotion matching task investigates categorical knowledge of emotion (i.e., the ability to visually discriminate basic emotions from one another). In these emotion tasks, five of the six basic facial expressions of emotion (happy, sad, anger, fear, surprise), as well as neutral facial expressions, were used. The facial expression of disgust was not used because as suggested by the literature (chapter 1) is not developed until the age of 11 or 12 and in this study of particular interest were the emotions that are recognized in middle childhood.

The CFT has not traditionally been used with children under 5 years of age. Given that this is the age where emotion is beginning to be clearly recognized, specifically happy facial expressions of emotion, this was the youngest age group chosen. However, as both emotion recognition and laterality for emotion processing develop over time for differing emotions, a longitudinal design was used. Groups of 5 to 6 year olds, 7 to 8 year olds, and 9 to 10 year olds were followed over a one year period, where it was expected this was sufficient time to assess changes in both recognition ability and hemispheric processing of emotion.

In exploring the predictive ability of strength of laterality, given that there are relationships between emotion recognition and age (e.g., Herba & Phillips, 2004), as well as strength of laterality and age (e.g., Workman et al., 2006), age will be controlled for as a variable. Additionally, as research with adults has found a relationship between sex and strength of laterality for emotion processing (e.g., Bourne, 2005), and research with children has found a relationship between sex and emotion recognition (see review by McClure, 2000), sex will be controlled for as a variable.

Specifically in this longitudinal study it is expected that, as shown by Bruce et al. (2000), there will be different rates of development of emotion processing skills in different tasks, across emotions and across different ages. Importantly, it is also expected that developmental changes in the strength of hemispheric laterality will positively predict greater emotion recognition skills at one year beyond strength of hemispheric lateralisation at baseline (after controlling for age, sex, and emotion task performance at baseline).

4.1.1 Method

Participants

Two hundred and thirteen children from two British Schools, one in a working class neighbourhood and of mixed ethnic background and one in a middle-class neighbourhood and primarily White British participated in the first time point of this study. Of these, complete data (participated at time 1 and one year later at time 2) were obtained from 169 children, resulting in an attrition rate of 20.7%. Analyses showed that those who were present and participated at both time 1 and 2 did not differ significantly on any of the time 1 measures from the children who participated only at time 1. The children at time 1 of the study were 51 six-year-olds (M = 6.32, range 5.9 to 6.9, 27 girls), 53 eight-year-olds (M=8.32, range 7.5 to 8.9, 26 girls) and 65 ten-year-olds (M= 10.33, range 9.4 to 10.9, 36 girls).These were tested again 356 days later.on the same tasks as time 1 of testing. The Heads in both schools preferred to use an opt-out form for consent; parents were sent information regarding the study and asked to return the form to the class teacher if they did not wish their child to participate. Verbal assent was also obtained from all the children. This study was approved by the Royal Holloway, Department of Psychology, Ethics Committee.

Participants who gave verbal assent to participate were asked individually to sign their name on the top half of a piece of paper and then were asked to pick up the child scissors and to cut the paper in half. The researcher recorded whether they used their right or left hand to write their name, use the scissors. Additionally, once the children were seated at the computer and used the mouse the researcher noted which hand (left or right) the child used. If a child used their left hand for any of the three tasks (writing their name, cutting the papers, clicking the mouse) their results were excluded from additional analyses. In total 12 children were excluded from the 169 children because of their handedness.

Material

Four tasks were used in this study, including the chimeric faces test (CFT, described in section 2.2.2, chapter 2) and three emotion recognition tasks: an emotion discrimination task, an emotion-matching task and an identity matching task adapted from Bruce et al. (2000, described in section 2.1, chapter 2). The stimuli used were black and white photographs of NIMH (National Institute of Mental Health) pictures, previously validated (chapter 2), displaying five basic emotional facial expressions (happy, sad, fearful, angry and surprised) and neutral. All faces expressed the emotion at 100% of intensity and posed in full frontal orientation with a black oval mask framing the face to remove additional features, such as hair and ears, thereby allowing children to focus on the internal features of the face and emotion. For the chimeric faces the happy and sad chimeras that were created for Study 1 and 2 were used, and angry chimeras were created in the same way as the happy and sad (as discussed in chapter 2).

Design and Procedure

Participants were seen either in small groups of four in a quiet area of the school or as a whole class in their school ICT suite. All children were informed about the study, and were given the opportunity to ask questions, as well as to opt out of the study. Children's handedness was assessed, as outlined in section 4.1.1. Once seated in front of the computer or laptop, children were asked to put on the headphones.

Children performed four tasks: i) a chimeric faces test (CFT) ii) an emotion discrimination task iii) an emotion-matching task and iv) an identity matching task.

The tasks were randomly presented to participants on a Dell Inspiron 15 inch laptop computer or a 15 inch desktop in the ICT suite of the school. Runtime Revolution 3.0 software allowed for simultaneous presentation of stimuli and verbal components (e.g., instructions) for each task via a set of headphones.

The order of the tasks for each child and the trials in each task were randomly assigned through the Revolution Studio programme. Upon completion of the tasks children were given the opportunity to ask any questions. The same set of tasks and procedure was used at both time points.

Children's responses were recorded by the software as they clicked their response on the mouse. For the three emotion recognition tasks children were provided with a mouse that had a green piece of paper on the left mouse button and a yellow piece of paper on the right mouse button (see Figure 4.1).

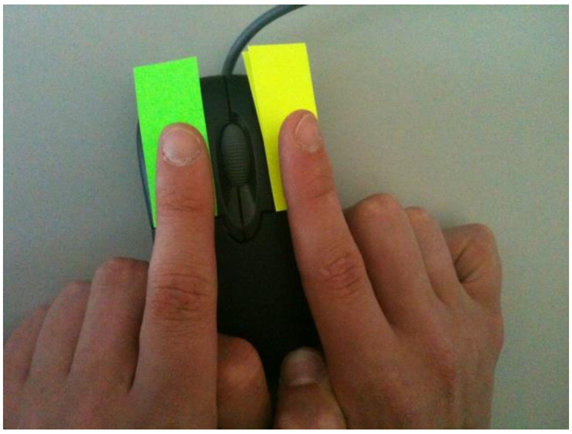

Figure 4. 1. Mouse set up.

Emotion discrimination task: Children in this task (described in section 2.1, chapter 2) were presented with a pair of full faces which were of the same sex. One face in the pair was depicted one of the six facial expressions as a target emotion (happy, sad, angry, fear, surprise and neutral) and it was paired with a different distracter non-target emotion. Children were asked to choose the face expressing the target emotion (Figure 4.2). In total there were 36 trials, 6 trials for each facial expression. In half of the trials a male identity was used and in half a female identity. There were two versions of the task created. In version 1 for 17 pairs the two faces were of the same identity expressing different emotions and for 19 pairs they were of different identities, while in version 2 for 19 pairs the two faces were of the same identity and 17 pairs were of different identities. The identity of the pairs was important as when it was the same individual in the pair it would be a more difficult trial (configural information of the face will interfere with emotion processing), while when it was different individuals in the pair it would be a simpler trial (focus would be on the emotion only).

Before beginning the children had five practice trials where feedback was given through the headphones only for wrong responses (“Are you sure you wanted to press that button? Try again!”). When children responded correctly on the practice trial the programme would automatically move to the next practice trial. After the practice trials a secondary instruction screen came up that reminded participants what they were required to do, including that they should put their left index finger on the green mouse button and their right index finger on the yellow mouse button (as shown in Figure 4.1). When children were ready they would press the ‘Begin’ button. Each trial started with the children hearing through the headphones the target emotion to look for (e.g., “Which face of the two faces do you think looks happy?”), and once the sentence through the headphones finished, the pair of stimuli appeared simultaneously on the screen (Figure 4.2). The trial ended when the participant made a response (the faces were presented until a response was made). Participants responded by clicking on the yellow mouse button if they wanted to choose the face on their right side or by clicking on the green mouse button if they wanted to choose the face on their left side). Once they responded the card would automatically change to another trial. Accuracy was recorded by the Runtime Revolution programme. Children received a score from 0 to 1. Participants received 1 if they clicked the correct response or 0 if they clicked the wrong response. Scores were subtotalled for each emotion, with scores ranging from 0 to 6, and a total emotion discrimination score ranging from 0 to 36 and percentage correct were calculated.

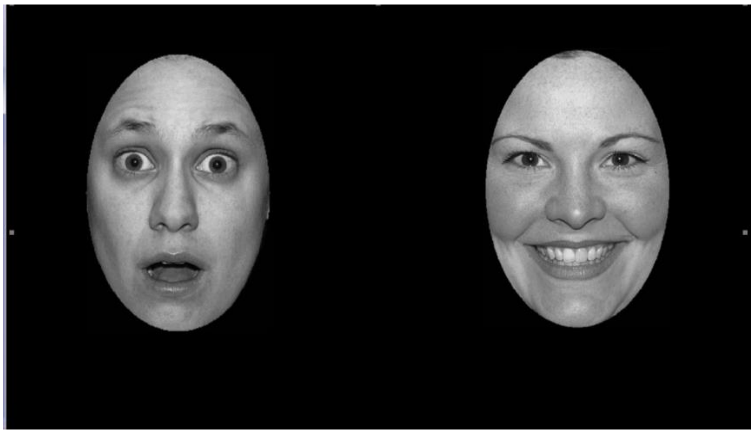

Figure 4. 2. Example of an emotion discrimination trial.

Explicit emotion-matching task: Three faces were presented on the screen. One at the top centre was the target stimulus and two faces at the bottom left and right of the screen were the choice stimuli (.section 2.1, chapter 2). Participants were asked to match the emotion of a target stimulus with one of two choice stimuli (Figure 4.3). The target stimulus was of the same sex as the two choice stimuli. In half of the trials the choice stimuli were of the same identity as the target stimulus and in half of the trials the three stimuli were of a different identity. (Bruce et al., 2000; De Sonneville et al., 2002). The target and one of the choice stimuli expressed the same emotion at 100% of intensity. In total there were 36 trials, 6 for each facial expression as target. In half of the trials, a female identity posing six facial expressions was used and in half a male identity was used. In version 1 of the task half of the trials had the correct choice on the left bottom side and half had the correct choice on the right bottom side. The reverse was the case in version 2 of the task (see Fig. 4.3).

Similarly to the task above, before beginning children had five practice trials where feedback was given through the headphones only for wrong responses (“Are you sure you wanted to press that button? Try again!”). When children responded correctly on the practice trial the programme would automatically move to the next practice trial. After the practice trials a secondary instruction screen came up that reminded participants what they were required to do, including that they should put their left index finger on the green mouse button and their right index finger on the yellow mouse button (as shown in Figure 4.1). When children were ready they would press the ‘Begin’ button. Each trial started with the children hearing through the headphones the instructions for the task. The trial ended when the participant made a response (the faces were presented until a response was made). Participants responded by clicking on the yellow mouse button if they wanted to choose the face on their right side or by clicking on the green mouse button if they wanted to choose the face on their left side). Once they responded the card would automatically change to another trial. Accuracy was recorded by the Runtime Revolution programme. Children received a score from 0 to 1. They received 1 if they clicked the correct response or 0 if they clicked the wrong response. Scores were subtotalled for each emotion, with scores ranging from 0 to 6, and a total emotion matching score, ranging from 0 to 36 and percentage correct were calculated.

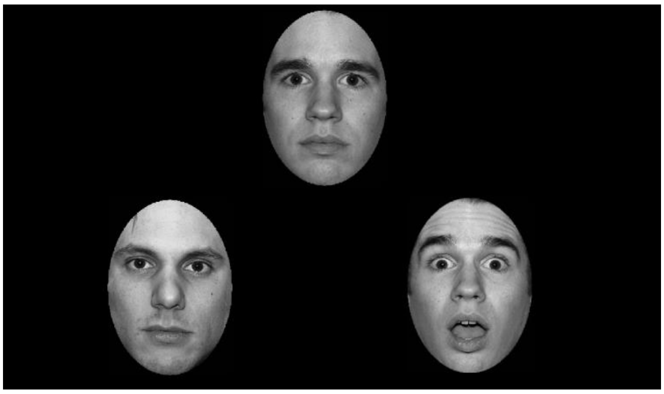

Figure 4. 3. Example of an emotion matching trial.

Implicit emotion-matching (identity matching) task: Three faces were presented on the screen. One at the top centre was the target stimulus with neutral expression and two faces at the bottom left and right of the screen were the choice stimuli. One of the choice stimuli was of the same identity as the target stimulus, but with a different facial expression from the target stimulus; the emotional expression was used as distracter to identity matching (see Figure 4.4, also section 2.1, chapter 2). Children were required to ignore the emotion, and to match the identity. The other choice stimulus was of different identity to the target stimulus but had the same neutral expression as the target stimulus. In identity matching tasks the sex of the stimuli always match (Bruce et al, 2000; De Sonneville et al., 2002). Therefore, the target stimulus was of the same gender as the two choice stimuli. There were a total of 22 trials. There were 11 male and 11 female identities, which when they were the correct choice posed five emotions and two neutral. In version 1 of the task half of the trials were the correct choice on the left bottom side and half were the correct choice on the right bottom side. The reverse was the case in version 2 of the task. All images were of the same size, subtending approximately 6° horizontally and 8.5° vertically. The order of trials was randomised by the computer programme.

Similarly to all tasks, before beginning children had five practice trials where feedback was given through the headphones only for the wrong responses ("Are you sure you wanted to press that button? Try again!"). When children responded correctly on the practice trial the programme would automatically move to the next practice trial. After the practice trials a secondary instruction screen came up that reminded participants what they were required to do, including that they should put their left index finger on the green mouse button and their right index finger on the yellow mouse button (as shown in Figure 4.1). When children were ready they would press the 'Begin' button. Each trial started with the children hearing through the headphones the instructions for the task. The trial ended when the participant made a response (the faces were presented until a response was made). Participants responded by clicking on the yellow mouse button if they wanted to choose the face on their right side or by clicking on the green mouse button if they wanted to choose the face on their left side). Once they responded the card would automatically change to another trial. Accuracy recorded by the Runtime Revolution programme. Children received a score from 0 to 1. They received 1 if they clicked the correct response or 0 if they clicked the wrong response. Scores were subtotalled for each emotion, with scores ranging from 0 to 5, and a total identity matching score ranged from 0 to 22, and percentage correct were calculated.

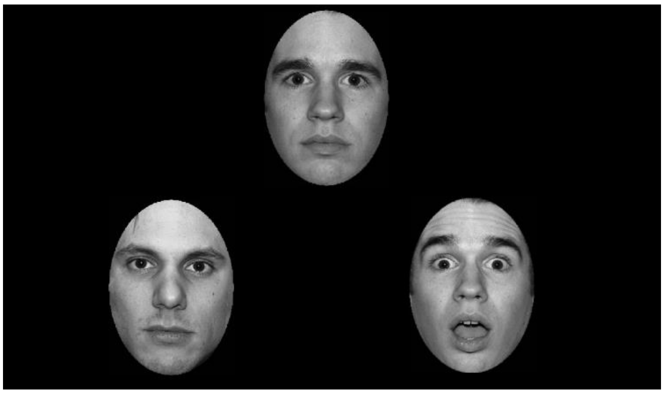

Figure 4. 4. Example of an identity matching trial.

Chimeric Faces Test (CFT): The CFT was used as a test of laterality. The task was administered in the same way as previously reported by Bourne (2005, also see section 2.2.2, chapter 2). Children were presented with pairs of chimeric faces, one above the other (Figure 4.5). Happy, sad and angry chimeras were used in the study. Each face subtended approximately 6.5°

horizontally and 9° vertically. The distance between the two faces was 0.001°. Each pair was presented twice, once with the original chimeric face (emotion in the LVF) at the top and its mirror (emotion in the RVF) at the bottom and once with the faces in the reversed place (mirror at the top and original at the bottom). Placement of the two faces was counterbalanced and was randomised between participants. The presentation of the stimuli was blocked by emotion with instructions prior to each block to keep children focused on the task, so there were three blocks (one each for happy faces, sad faces, and angry faces). Within each block there were 12 trials for each emotion. The order of presentation of the blocks, and the order of trials within the blocks was randomised by the Runtime Revolution program. In each trial, children were asked to concentrate on the faces and decide which they thought looked happier, sadder or angrier and click on their choice. When each pair was presented at the centre of the screen the cursor was positioned in the middle between the two faces. In that way any upward movement would enable children to click on the top face and any downward movement would enable them to click on the bottom face. The pictures stayed on the screen until the children responded. From the responses a laterality quotient (CFT-LQ) was calculated in the same way as in Bourne, (2005) and the validation study (chapter 2) ranging from -1 to +1 (-1: always chose the emotion in the right visual field indicating left hemisphere advantage, +1: always chose the emotion in the left visual field, indication of right hemisphere dominance). A laterality quotient was computed for each of the three emotions, as well as a total laterality quotient.

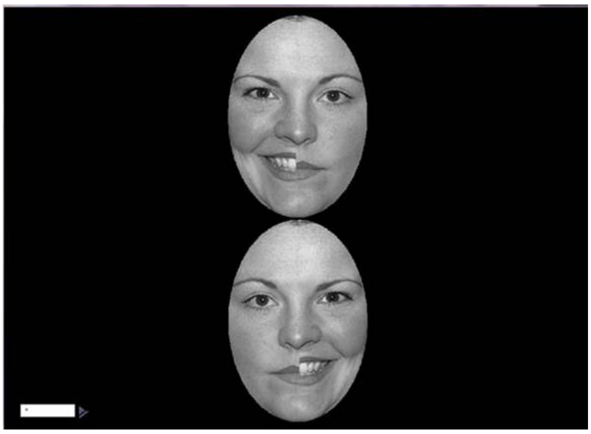

Figure 4. 5. Example of a CFT trial.

4.1.2 Results

Laterality Quotients

Mean laterality quotients for each of the three emotions were calculated for both, Time1 and Time2 of testing and are presented in Table 4.1. At both time points, the mean laterality quotients for all three emotions were significantly greater than zero (see Table 4.1), indicating that participants tended to have a right hemisphere bias for emotion processing of happy, sad, and angry faces. In addition to this, separate one-sample t-tests on the laterality quotients for each emotion, with zero as the reference category, were completed for each age group and at each time point. Results indicated that for only the 6 year olds was there a non-significant finding; in fact, the laterality quotient for the sad emotion, at time 1 of testing, showed no significant bias in the processing (not significantly different from zero), *t* (.44) = 1.60, *p* = .104.

		N	Mean	SD	*t*	df	*p*
Laterality Quotient at Time 1	Happy	149	0.17	0.34	6.36	148	<.001
	Sad	149	0.14	0.26	6.89	148	<.001
	Angry	149	0.15	0.24	7.82	148	<.001
Laterality Quotient at Time 2	Happy	149	0.16	0.29	6.97	148	<.001
	Sad	149	0.18	0.26	8.75	148	<.001
	Angry	149	0.2	0.29	8.53	148	<.001

Table 4. 1. Mean laterality quotients for happy, sad and angry and one-sample t tests comparing laterality quotients to 0 at two time points.

Laterality quotients for processing facial expressions of happy, sad and angry emotions were subsequently analysed using a 2 (Time: 1, 2) x 3 (emotions: happy, sad, angry) x 3 (age group: 6-, 8- and 10-year-olds) x 2 (sex: male, female) mixed ANOVA. Neither the main effect of age group, *F* (2,143) = 0.15, *p* = .860, η^2 = .002, the main effect of sex, *F* (1, 452) = 0.57, *p* = .452, η^2 = .004, nor the interaction between sex and age group, *F* (2,143) = 0.10, *p* = .900, η^2 = .001, was significant. There was a significant interaction for age group x emotion, *F* (4,286) = 2.48, *p* = .044, η^2 = .034. There was further a 3 way interaction for time x emotion x age group significant interaction. Further analysis showed that the interaction between emotion and age group was marginally significant at time 1 of testing, *F* (3.57, 298.07) = 2.41, *p* = .056, η^2 = .028 but the interaction was not significant for time 2, *F* (3.85, 382.83) = 1.99, *p* = .099, η^2 = .020. Pairwise comparisons on the simple effects, Bonferroni corrected, showed that at time 1 of testing the interaction was driven by the laterality for processing sad emotion being significantly different only between the 6- and the 10-year-group children. The 6 year olds were significantly less lateralised than the 10 year olds (p = .010), at time 1, whereas there was no significant difference in laterality for processing sad facial expressions between the two older groups of children, p = .258 (Figure 4.6). The difference between the laterality for processing sad facial expressions only in time 1 indicates the laterality development for sad facial expressions between the ages of 6 to 10 years. For the emotion of anger, the 8-year-olds, were significantly more right hemisphere lateralised at time 2 of testing than at time 1 (p = .007, Figure 4.6)

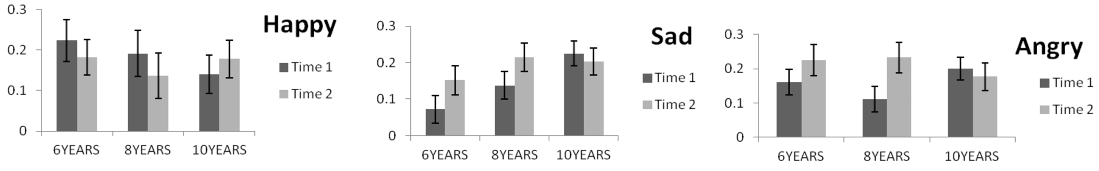

Figure 4. 6.Laterality for happy, sad and anger processing for the 3 age groups across the two time points of testing with standard error bars, p < .05.

Emotion Discrimination Task

The percentage correct of the scores recorded at Time 1 and Time 2 were analysed using a 2 (time: 1, 2) x 6 (emotions: happy, sad, angry, fear, surprise, neutral) x 3 (age group: 6-, 8- and 10-year-olds) x 2 (sex: male, female) mixed ANOVA. The main effect of time was significant, *F* (1,142) = 12.09, *p* = .001, η^2 = .078, where children were more accurate in discriminating the facial expressions of emotion at time 2 (M = 93.4%, SE = 0.51) of testing in comparison to time 1 (M = 90.2% SE = 0.93). There was a significant main effect of age group, *F* (2,142) = 5.67, *p* = .004, η^2 = .074 (see Figure 4.7). Helmert contrasts showed that the 6 year olds were less accurate, approaching significance, than the 8- and 10-year-old children combined, p = .052, and 8-year-old children were significantly less accurate than the 10 year olds, p = .009.

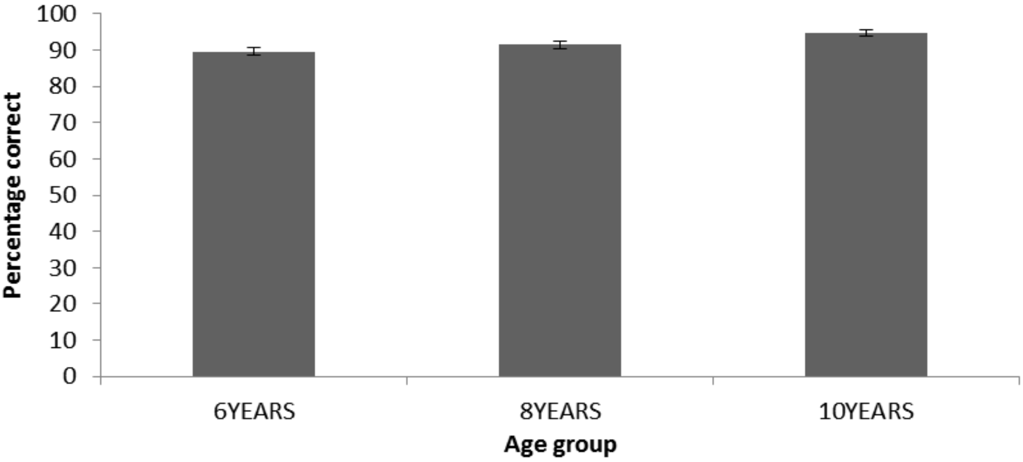

Figure 4. 7. Emotion Discrimination Task: Accuracy performance (% correct) of the three age groups combined across the two times of testing with standard errors, p < .05.

The main effect of emotion was also significant, *F* (4.20, 609.52) = 50.46, *p* < .001, η^2 =.259 with fear being significantly more difficult (less accurate) to discriminate than all other emotions (p <. 001), which were close to ceiling (Figure 4.8). There were no significant interactions.

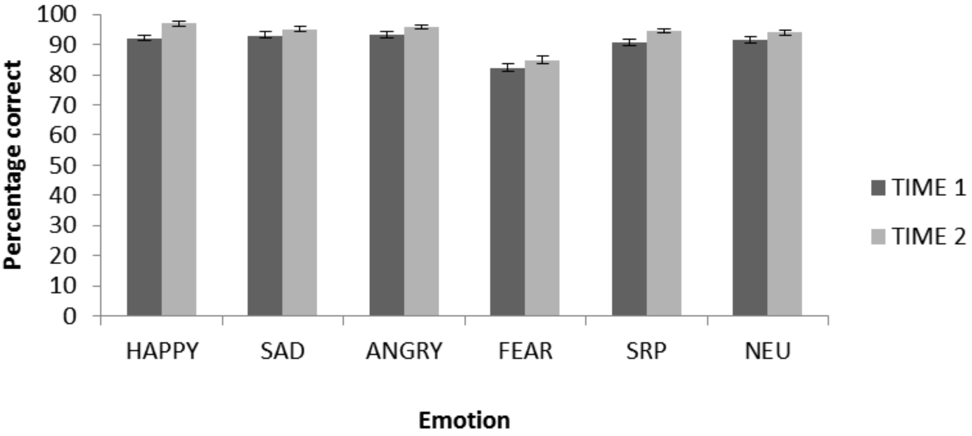

Figure 4. 8. Emotion discrimination task: Percentage correct at two time points of testing for the different emotions combined across age groups with standard error, p < .05.

Emotion Matching Task

The percentage correct of the scores recorded at Time 1 and Time 2 were analysed using a 2 (time: 1, 2) x 6 (emotions: happy, sad, angry, fear, surprise, neutral) x 3 (age group: 6-, 8- and 10-year-olds) x 2 (sex: male, female) mixed ANOVA. The main effect of age group was significant, *F* (2,141) = 6.31, *p* = .001, η^2 = .082 (see Figure 4.9). Helmert contrasts showed that the 8-year-old children were significantly less accurate than 10-year-old children, p = .002 but 6 year olds were not significantly different from 8-year-old and 10-year-old groups combined, p = .165. The main effect of sex was also significant, *F* (1,141) = 9.227, *p* = .003, η^2 = .061, whereby girls (M = 82.32%, SE = 1.2) were more accurate than boys (M= 76.72%, SE = 1.3). The interaction between age group and sex was significant, *F* (1,141) =

3.24, *p* = .042, η^2 = .042. Pairwise comparisons, Bonferroni corrected, indicated that only 6- and 8-year-old girls (M = 81.43%, SE = 2.3 and 81.88%, SE = 2.2, respectively) were more accurate than 6- and 8-year-old boys (M = 73.86%, SE = 2.4 and 72.03%, SE = 2.3, respectively), (see Figure 4.10)

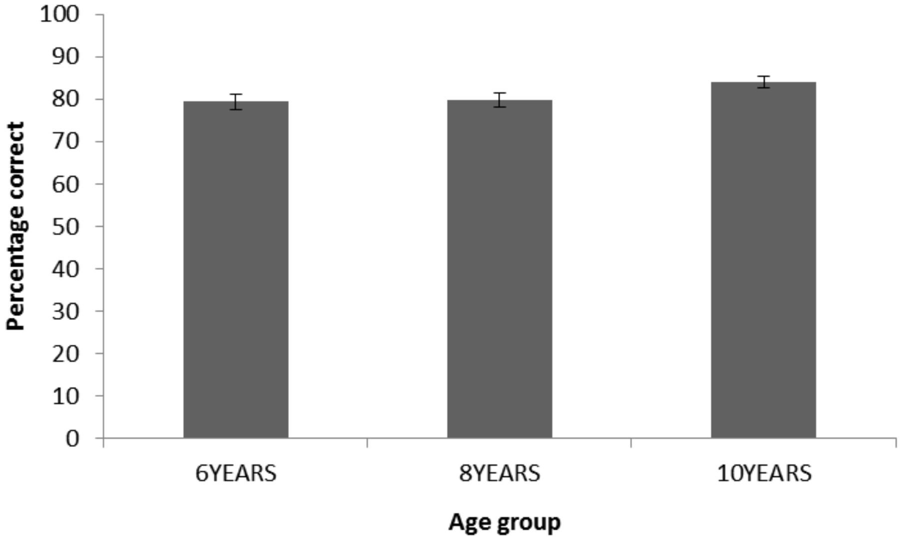

Figure 4. 9.Emotion Matching Task: Accuracy performance (% correct) of the three age groups across the two times of testing.

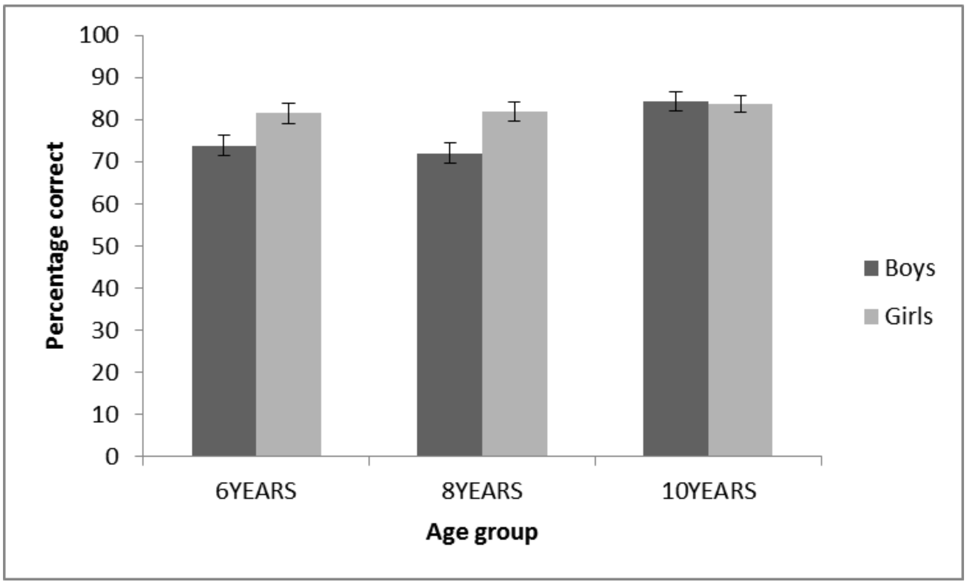

Figure 4. 10.Emotion Matching Task: Sex differences in the three age groups.

The main effect of time was significant, *F* (1,141) = 45.19, $p < .001$, $\eta^2 = .215$, as well as the main effect of emotion, *F* (4.01, 565.82) = 39.24, $p < .001$, $\eta^2 = .218$. These main effects were qualified by a significant time x emotion interaction, *F* (4.27, 602.46) = 35.37, $p < .001$, $\eta^2 = .201$. Pairwise comparisons showed that, overall, children performed significantly better at time 2 when they matched happy, sad, and angry expressions (all p values < .001). The matching of fearful, surprised and neutral expressions did not differ significantly between the two testing times (all p values >. 150, Figure 4.11). There were no significant interactions.

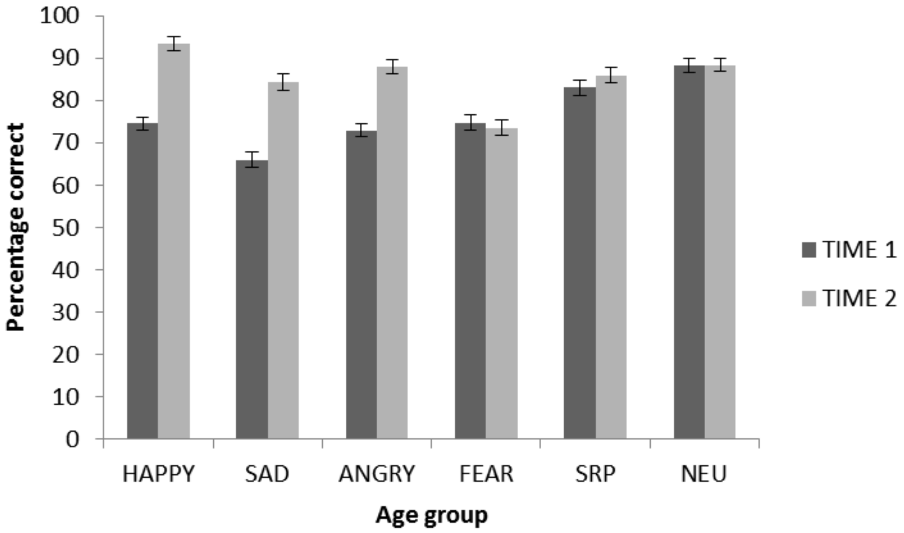

Figure 4. 11. Emotion matching task: Percentage correct for different emotions at two time points with standard errors, p < .05.

Identity Matching Task

Similarly to the previous analysis, the percentage correct of the scores recorded at Time 1 and Time 2 were analysed using a 2 (time: 1, 2) x 6 (emotions: happy, sad, angry, fear, surprise, neutral) x 3 (age group: 6-, 8- and 10-year-olds) x 2 (sex: male, female) mixed ANOVA. There was a significant main effect of time, F (1,145) = 4.03, p = .046, η^2 = .027 and significant main effect of emotion F (3.13, 454.20) = 27.47, p <.001.159, η^2 = .159. These main effects were qualified by a significant time x emotion interaction, F (3.59, 521.38) = 4.76, p =.001, η^2 = .032. Children significantly improved from time 1 to time 2 in matching identities when the distractor was the emotion of sad only and not for other distraction emotions (M time 1 =

40.3%, SE = 1.7; M time 2 = 56.4% SE = 2; p <.001)) (Figure, 4.12). The main effect of year group was significant, *F* (2,145) = 9.32, *p* < .001, η^2 = .120. Helmert contrasts showed that 6 year olds were significantly less accurate to match faces with different facial expressions than the 8- and 10-year-old children combined, p<.001, and the 8-year-olds were significantly different in accuracy from the 10-year-olds, p = .027 (see Figure 4.13).

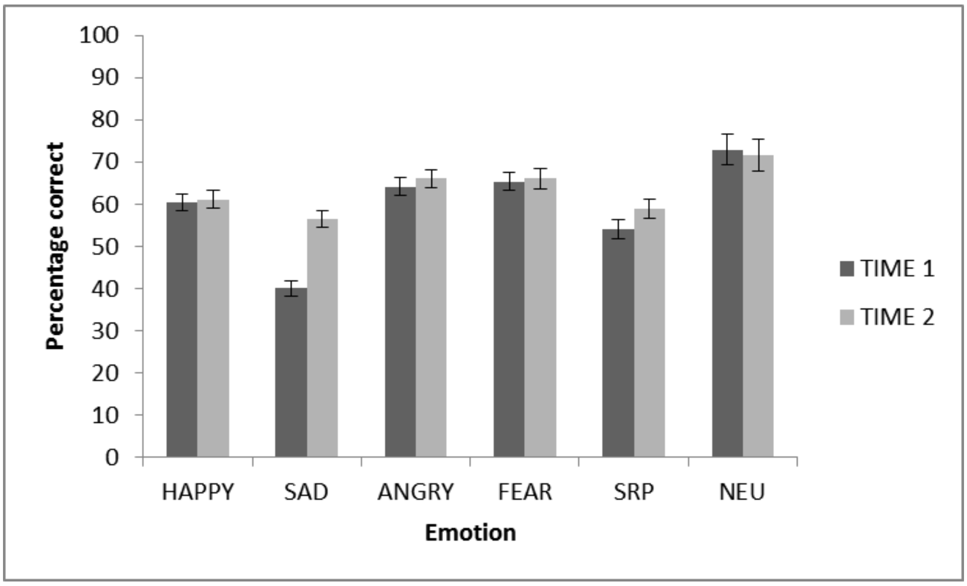

Figure 4. 12.Identity matching task: Percentage correct for different emotions at two time points with standard errors, p < .05

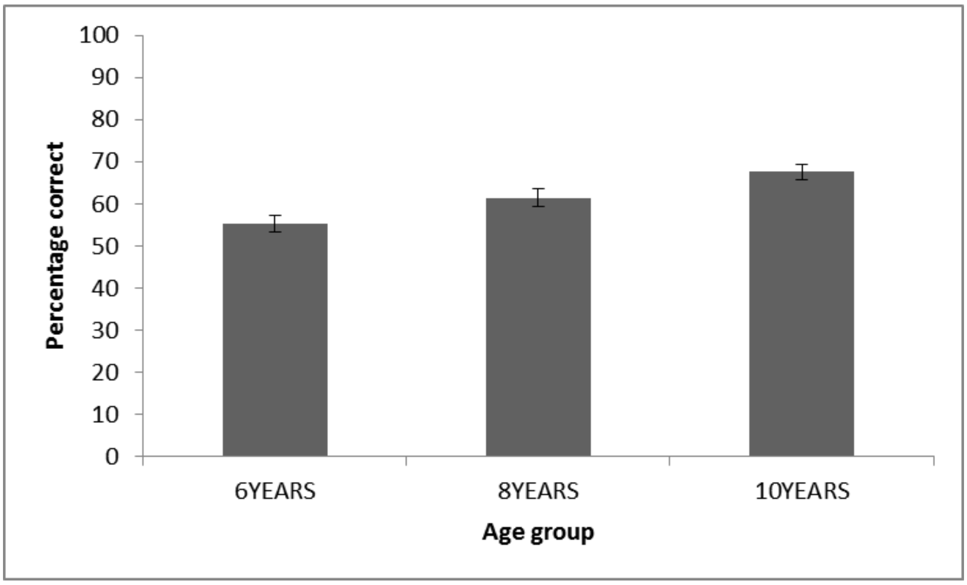

Figure 4. 13. Identity matching task: Percentage correct for three age groups with standard errors, p < .05.

Emotion recognition and emotion lateralisation

One of the main aims of this research was to investigate whether laterality and changes in laterality predict task performance over one year period. In an initial analysis for each of the emotion recognition tasks separate hierarchical regression analysis was used with emotion recognition task accuracy (total percentage correct) as the outcome variable (i.e., emotion discrimination, emotion matching, and identity matching). For each regression there were three blocks. The first block included control predictors (age group, sex and task performance at time 1). The second block included the additional predictors for laterality at time 1 (laterality quotient at time 1, the interaction between laterality quotient at time 1 and age group, and the interaction between laterality quotient at time 1 and sex). The third block included the additional predictors for laterality change: laterality difference, the interaction between laterality difference and age group, and interaction between laterality difference and sex. A laterality difference score was computed by subtracting time 2 laterality quotient minus time 1 laterality quotient. This was done to assess how developmental changes in the strength of laterality from time 1 to time 2 influenced task performance.

In a subsequent analysis for each of the emotion recognition tasks and for happy, sad and angry emotions, separate hierarchical regression analysis was performed with each emotion's recognition task accuracy (total percentage correct) as the outcome variable (i.e., in emotion discrimination, emotion matching, and identity matching). This analysis was performed only for the three emotions for which laterality quotients were obtained. As explained in section 4.1 angry was chosen as an appropriate emotion to explore alongside sad and happy emotions because they have been shown to become lateralised earliest (Workman et al., 2006). Furthermore the three emotions were chosen due to testing constraints, the emotion processing of fear and surprise using the CFT was not included within the design.

Emotion Discrimination Task

Table 4.2 gives the zero-order correlations between all continuous measures entered into the regression models. The regression analysis findings are presented in Table 4.3. The first block, containing age group, sex and performance at time 1, was significantly better than chance at predicting emotion discrimination performance at time 2, *F* (3, 143) = 3.99, *p* = .009, explaining 5.8% of the variance. Performance at time 1 was a significant predictor: the greater the accuracy at time 1 the better the performance at time 2. Sex was a significant predictor. Age was not a significant predictor. The second block, with the addition of lateralisation at time 1 and interactive predictors, was a significant improvement on the model, explaining a further 8.8% of the variance, *F* (6, 140) = 4.63, *p* < .001. The third block containing laterality difference between laterality at time 1 and time 2 of testing and its interactions with age group and sex was not a significant improvement on model 2. The overall model explained 13% (Adjusted R^2) of the variability in the ability to discriminate the facial expressions of emotion.

Thus significant predictors in the model of emotion discrimination included, sex, performance at time 1 and laterality at time 1. This analysis shows that girls tended to perform better than boys, and that higher performance at time 1 significantly predicted higher performance at time 2. Importantly, the strength of lateralisation at time 1 was a significant predictor, showing a positive relationship whereby the more right hemisphere lateralised a child was at time 1 the more accurately the child performed at time 2. None of the interactive predictors was significant.

	Performance time 2	age	Performance time 1	Laterality time 1	Laterality time2-time1
Performance time 2		0.129	0.211**	0.240**	-0.132
age			0.278**	0.064	-0.051
Performance time 1				0.079	-0.058
Laterality time 1					-0.411**
Laterality time2-time1					

Table 4. 2. Zero-order correlations between continuous measures (= p<.010).**

Model		Beta	t	p
1	age	.082	.990	.323
	sex	.163	2.010	**.046**
	Performance time 1	.175	2.110	**.036**
2	age	.196	1.940	.054
	sex	.275	2.760	**.007**
	Performance time 1	.154	1.927	.056
	Laterality time 1	1.473	2.800	**.006**
	Laterality time 1 x age	-.852	-1.950	.053
	Laterality time 1 x sex	-.445	-1.700	.090
3	**age**	.198	1.800	.073
	sex	.265	2.470	.**015**
	Performance time 1	.156	1.930	.055
	Laterality time 1	1.46	2.340	.**021**
	Laterality time 1 x age	-.881	-1.720	.088
	Laterality time 1 x sex	-.414	-1.420	.157
	Laterality Difference	-.021	-.040	.965
	Laterality Difference x age	-.136	-.290	.767
	Laterality Difference x sex	.129	.430	.667

Table 4. 3. Emotion Discrimination Task: Predictors of accuracy entered into the model

Emotion Matching Task

Table 4.4 gives the zero-order correlations between all continuous measures entered into the regression models. The regression analysis findings are presented in Table 4.5. The first block, containing age group, sex and performance at time 1, was significantly better than chance at predicting emotion matching performance at time 2, *F* (3, 142) = 9.80, *p* <.001, explaining 15.4% of the variance. Performance at time 1 was a significant predictor: the greater the accuracy at time 1 the better the performance at time 2. Age was a significant predictor. Sex was not a significant predictor. The second block, with the addition of lateralisation at time 1 and interactive predictors, was not a significant improvement on model 1. The third block containing laterality difference between laterality at time 1 and time 2 of testing and its interactions with age group and sex was not a significant improvement on model 2. The overall model explained 15.4 % (Adjusted R^2) of the variability in the ability to match the facial expressions of emotion.

The significant predictors in the model of emotion matching included, age, performance at time 1 and laterality difference between laterality at time 2 – laterality at time 1. This analysis shows that children perform better with age and that higher performance at time 1 significantly predicted higher performance at time 2. Importantly, the laterality quotients' difference between time 1 and time 2 of testing was a significant predictor showing a positive relationship whereby the more right hemisphere lateralised a child was at time 2 the more accurately the child performed the task at time 2. None of the interactive predictors were significant.

	Performance Time 2	age	Performance time 1	Laterality time 1	Laterality time2-time1
Performance time 2		0.298**	0.348**	0.107	0.050
age			0.266**	0.064	-0.051
Performance time 1				0.096	-0.151
Laterality time 1					-0.411**
Laterality time2-time1					

Table 4. 4. Zero-order correlations between continuous measures (= p<.010).**

Model		Beta	t	p
1	**age**	.228	2.920	**.004**
	sex	.049	.640	.520
	Performance time 1	.291	3.730	**<.001**
2	**age**	.207	2.070	**.040**
	sex	-.065	-.650	.513
	Performance time 1	.292	3.720	**<.001**
	Laterality time 1	-.517	-.960	.336
	Laterality time 1 x age	.127	.290	.772
	Laterality time 1 x sex	.479	1.890	.060
3	**age**	.286	2.700	**.008**
	sex	-.008	-.080	.935
	Performance time 1	.299	3.860	**<.001**
	Laterality time 1	.138	.230	.818
	Laterality time 1 x age	-.326	-.660	.504
	Laterality time 1 x sex	.307	1.120	.262
	Laterality Difference	1.070	2.300	**.023**
	Laterality Difference x age	-.618	-1.450	.147
	Laterality Difference x sex	-.331	-1.200	.231

Table 4. 5. Emotion Matching Task: Predictors of accuracy entered into the models.

Identity Matching Task

Table 4.6 gives the zero-order correlations between all continuous measures entered into the regression models. The regression analysis findings are presented in Table 4.7. The first block, containing age group, sex and performance at time 1, was significantly better than chance at predicting identity matching performance at time 2, *F* (3, 146) = 4.17, *p* =.007, explaining 6% of the variance. Age was a significant predictor with children performing better with increasing age. Sex was not a significant predictor. The second block, with the addition of lateralisation at time 1 and interactive predictors, was not a significant improvement on model 1. The third block containing laterality difference between laterality at time 1 and time 2 of testing and its interactions with age group and sex was not a significant improvement on model 2. The overall model explained 6% (Adjusted R^2) of the variability in the ability to match the facial identities with facial expressions. The significant predictor in the model of identity matching was age.

	Performance time 2	age	Performance time 1	Laterality time 1	Laterality time2-time1
Performance time 2		0.245**	0.191	-0.003	-0.047
age			0.339	0.064	-0.051
Performance time 1				0.07	-0.008
Laterality time 1					-0.411**
Laterality time2-time1					

Table 4. 6. Zero-order correlations between continuous measures (= p<.010).**

Model		Beta	t	p
1	**age**	.217	2.58	**.011**
	sex	.096	1.19	.232
	Performance time 1	.074	.88	.380
2	age	.108	1.01	.313
	sex	.120	1.14	.254
	Performance time 1	.083	.97	.331
	Laterality time 1	-.616	-1.08	.278
	Laterality time 1 x age	.747	1.60	.110
	Laterality time 1 x sex	-.091	- .33	.738
3	age	.067	.59	.556
	sex	.090	.79	.427
	Performance time 1	.071	.81	.416
	Laterality time 1	- .960	-1.47	.143
	Laterality time 1 x age	.999	1.88	. 61
	Laterality time 1 x sex	.002	.01	.995
	Laterality Difference	- .554	-1.08	.279
	Laterality Difference x age	.390	.83	.406
	Laterality Difference x sex	.139	.46	.643

Table 4. 7: Identity Matching Task: Predictors of accuracy entered into the models.

Emotion recognition and emotion lateralisation: Developments for happy, Sad and Angry facial expressions of emotion.

One of the main aims of this research was to investigate whether laterality and changes in laterality predict task performance over a one year period. For of each of the emotion recognition tasks and for happy, sad and angry emotions, separate hierarchical regression analysis was performed with each emotion's recognition task accuracy (total percentage correct) as the outcome variable (i.e., in emotion discrimination, emotion matching, and identity matching). The analysis was performed only for the three emotions for which laterality quotients were calculated. Thus, fear and surprise were not analysed. For each regression there were three blocks. The first block included control predictors (age group, sex and task performance at time 1). The second block included the additional predictors for laterality at time 1 predictors (laterality quotient at time 1, the interaction between laterality quotient at time 1 and age group, and the interaction between laterality quotient at time 1 and sex). The third block included the additional predictors for laterality change, where a laterality difference score was computed, time 2 minus time 1 (LQ2 – LQ1), to assess how developmental changes in the strength of laterality from time 1 to time 2 influenced task performance (laterality difference, the interaction between laterality difference and age group, and interaction between laterality difference and sex).

Emotion Discrimination

Happiness

Table 4.8 gives the zero-order correlations between all continuous measures entered into the regression models. The regression analysis findings are presented in Table 4.9. The first block, containing age group, sex and performance at time 1, was marginally better than chance at predicting happy discrimination performance at time 2, *F* (3, 136) = 2.66, *p* = .051, explaining 5.5% of the variance. The second block, with the addition of lateralisation at time 1 and interactive predictors, was not a significant improvement on model 1. The third block containing the laterality difference between laterality at time 1 and time 2 of testing and its interactions with age group and sex was not a significant improvement on model 2. The predictor, which approached significance in the model of happy discrimination, was performance at time 1; higher performance at time 1 significantly predicted higher performance at time 2.

	Performance Time 2	age	Performance time 1	Laterality time 1	Laterality time2-time1
Performance time 2		0.146	0.203**	0.043	-0.006
age			0.215**	-0.102	0.06
Performance time 1				0.153	-0.066
Laterality time 1					-0.626**
Laterality time2-time1					

Table 4. 8. Zero-order correlations between behavioural and neuropsychological measures (= p<.010).**

Model		Beta	t	P
1	age	.106	1.240	.217
	sex	.054	.630	.528
	Performance time 1	.170	1.960	.051
2	age	.143	1.370	.173
	sex	- .004	- .03	.971
	Performance time 1	.155	1.700	.090
	Laterality time 1	- .031	- .050	.958
	Laterality time 1 x age	- .280	- .550	.578
	Laterality time 1 x sex	.358	1.190	.236
3	age	.148	1.29	.197
	sex	.019	.180	.856
	Performance time 1	.145	1.570	.119
	Laterality time 1	.145	.190	.847
	Laterality time 1 x age	- .307	- .480	.628
	Laterality time 1 x sex	.215	.560	.574
	Laterality Difference	.250	.390	.691
	Laterality Difference x age	.062	.100	.915
	Laterality Difference x sex	- .288	- .750	.450

Table 4. 9. Happy Discrimination Task: Predictors of accuracy entered into the models.

Sadness

Table 4.10 gives the zero-order correlations between all continuous measures entered into the regression models. The regression analysis findings are presented in Table 4.11. The first block, containing age group, sex and performance at time 1, was not significantly better than chance at predicting sad discrimination performance at time 2.The second block, with the addition of lateralisation at time 1 and interactive predictors, was not a significant improvement on model 1. The third block containing laterality difference between laterality at time 1 and time 2 of testing and its interactions with age group and sex was not a significant improvement on the model. None of the predictors was significant.

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	Performance time 2	age	Performance time 1	Laterality time 1	Laterality time2-time1
Performance time 2		0.113	0.169	0.126	-0.044
age			0.175	0.143	-0.063
Performance time 1				0.022	-0.014
Laterality time 1					-0.537**
Laterality time2-time1					

Table 4. 10. Zero-order correlations between behavioural and neuropsychological measures (= p<.010).**

Model		Beta	t	p
1	Age	.087	1.040	.300
	Sex	-.023	-.270	.780
	Performance time 1	.155	1.850	.060
2	age	.116	1.180	.230
	sex	-.013	-.130	0.890
	Performance time 1	.153	1.820	.070
	Laterality time 1	.563	1.100	.260
	Laterality time 1 x age	-.424	-.940	.340
	Laterality time 1 x sex	-.046	-.160	.870
3	age	.147	1.360	.170
	sex	-.050	-.470	.630
	Performance time 1	.159	1.87	.060
	Laterality time 1	.664	.990	.320
	Laterality time 1 x age	-.647	-1.13	.250
	Laterality time 1 x sex	.099	.290	.770
	Laterality Difference	.191	.31	.750
	Laterality Difference x age	-.513	-.92	.350
	Laterality Difference x sex	.366	1.12	.260

Table 4. 11. Sad Discrimination Task: Predictors of accuracy entered into the models.

Anger

Table 4.12 gives the zero-order correlations between all continuous measures entered into the regression models. The regression analysis findings are presented in Table 4.13. The first block, containing age group, sex and performance at time 1, was not significantly better than chance at predicting angry discrimination performance at time 2. The second block, with the addition of lateralisation at time 1 and interactive predictors, was not a significant improvement on model 1. The third block containing laterality difference between laterality at time 1 and time 2 of testing and its interactions with age group and sex was not a significant improvement on the model. None of the predictors was significant.

	Performance time 2	age	Performance time 1	Laterality time 1	Laterality time2-time1
Performance time 2		.041	0.104	0.151	0.037
age			0.152	0.086	-0.152
Performance time 1				0.012	-0.029
Laterality time 1					-0.465**
Laterality time2-time1					

Table 4. 12. Zero-order correlations between continuous measures (= p<.010).**

Model		Beta	t	p
1	age	.024	.280	.777
	sex	.038	.450	.648
	Performance time 1	.101	1.200	.231
2	age	.043	.420	.670
	sex	.088	.900	.369
	Performance time 1	.096	1.140	.255
	Laterality time 1	.663	1.160	.248
	Laterality time 1 x age	-.276	-.570	.564
	Laterality time 1 x sex	-.264	-.930	.352
3	age	.067	.590	.552
	sex	.084	.790	.429
	Performance time 1	.096	1.120	.261
	Laterality time 1	.770	1.170	.241
	Laterality time 1 x age	-.330	-.570	.569
	Laterality time 1 x sex	-.254	-.790	.426
	Laterality Difference	.232	.390	.690
	Laterality Difference x age	-.085	-.160	.873
	Laterality Difference x sex	-.008	-.020	.978

Table 4. 13. Angry Discrimination Task: Predictors of accuracy entered into the models.

Emotion Matching

Happiness

Table 4.14 gives the zero-order correlations between all continuous measures entered into the regression models. The regression analysis findings are presented in Table 4.15. The first block, containing age group, sex and performance at time 1, was significantly better than chance at predicting happy matching performance at time 2, *F* (3, 136) = 14.84, *p*<.001, explaining 23.4% of the variance. Performance at time 1 was a significant predictor; the greater the accuracy at time 1 the better the performance at time 2. Age was a significant predictor. The second block, with the addition of lateralisation at time 1 and interactive predictors, was not a significant improvement on model 1. The third block containing laterality difference between laterality at time 1 and time 2 of testing (LQ2 – LQ1) and its interactions with age group and sex was not a significant improvement on model 2. The overall model explained 23.4 % (Adjusted R^2) of the variability in the ability to match happy facial expressions.

The significant predictors in the model of emotion matching included age and performance at time 1. This analysis shows that children become better at matching happy facial expressions as they become older and that higher performance at time 1 significantly predicted higher performance at time 2.

	Performance time 2	age	Performance time 1	Laterality time 1	Laterality time2-time1
Performance time 2		0.225**	0.479**	0.111	-0.020
age			0.202**	-0.065	0.041
Performance time 1				0.134	-0.071
Laterality time 1					-0.635**
Laterality time2-time1					

Table 4. 14. Zero-order correlations between behavioural and neuropsychological measures (= p<.010).**

Model		Beta	t	p
1	age	.134	1.750	.081
	sex	-.004	-.050	.955
	Performance time 1	.452	5.940	**<.001**
2	**age**	.212	2.400	**.017**
	sex	.002	.020	.984
	Performance time 1	.429	5.530	**<.001**
	Laterality time 1	.795	1.530	.128
	Laterality time 1 x age	-.692	-1.640	.102
	Laterality time 1 x sex	-.053	-.200	.842
3	**age**	.239	2.45	**.015**
	sex	-.015	-.150	.874
	Performance time 1	.419	5.330	**<.001**
	Laterality time 1	.998	1.450	.149
	Laterality time 1 x age	-.947	-1.690	.092
	Laterality time 1 x sex	.075	.210	.829
	Laterality Difference	.279	.460	.644
	Laterality Difference x age	-.367	-.710	.476
	Laterality Difference x sex	.189	.570	.565

Table 4.15. Happy matching: Predictors entered in the models.

Sadness

Table 4.16 gives the zero-order correlations between all continuous measures entered into the regression models. The regression analysis findings are presented in Table 4.17. The first block, containing age group, sex and performance at time 1, was significantly better than chance at predicting emotion matching performance at time 2, *F* (3, 142) = 2.91, *p* = .036, explaining 3.8% of the variance. Age was a significant predictor. The second block, with the addition of lateralisation at time 1 and interactive predictors, was not a significant improvement on model 1. The third block containing LQ2 – LQ1 and its interactions with age group and sex was not a significant improvement on model 2. The overall model explained 3.8 % (Adjusted R^2) of the variability in the ability to match the facial expressions of sad.

The significant predictors in the model of emotion matching were, age, and most importantly laterality difference between laterality at time 1 and time 2 of testing and its interactions with sex. The significant interaction was broken down by comparing the correlations between sadness matching and change in lateralisation for sad expression separately for boys and girls. There was positive significant correlation only for boys, t (66) = .209, p = .046 but not for girls, t (80) = -.129, p = .126. This analysis shows that LQ2 – LQ1 was a significant predictor of boys' performance but not that of girls.

	Performance time 2	age	Performance time 1	Laterality time 1	Laterality time2-time1
Performance time 2		0.201**	0.153	-0.72	0.037
age			0.247**	0.175	-0.065
Performance time 1				-0.036	0.011
Laterality time 1					-0.525**
Laterality time2-time1					

Table 4. 16. Zero-order correlations between behavioural and neuropsychological measures (= p<.010)**

Model		Beta	t	p
1	**age**	.178	2.110	**.036**
	sex	.079	.950	.341
	Performance time 1	.098	1.150	.251
2	age	.162	1.670	.096
	sex	.055	.570	.569
	Performance time 1	.089	1.040	.299
	Laterality time 1	-.514	-.990	.320
	Laterality time 1 x age	.343	.790	.430
	Laterality time 1 x sex	.095	.330	.739
3	age	.198	1.870	.063
	sex	.157	1.500	.134
	Performance time 1	.118	1.370	.171
	Laterality time 1	.318	.466	.642
	Laterality time 1 x age	-.073	-.130	.895
	Laterality time 1 x sex	-.371	-1.100	.273
	Laterality Difference	1.150	1.840	.067
	Laterality Difference x age	-.429	-.800	.421
	Laterality Difference x sex	-.776	-2.430	**.016**

Table 4. 17. Sad matching: Predictors entered in the models.

Anger

Table 4.18 gives the zero-order correlations between all continuous measures entered into the regression models. The regression analysis findings are presented in Table 4.19. The first block, containing age group, sex and performance at time 1, was significantly better than chance at predicting angry matching performance at time 2, *F* (3, 142) = 3.37, *p* = .020, explaining 4.7% of the variance. Performance at time 1 was significant predictor: the greater the accuracy at time 1 the better the performance at time 2. Age was a significant predictor. Sex was not a significant predictor. The second block, with the addition of lateralisation at time 1 and interactive predictors, was not a significant improvement on model 1. The third block containing LQ2 – LQ1 and its interactions with age group and sex did was not a significant improvement on model 2. The overall model explained 4.7 % (Adjusted R^2) of the variability in the ability to match angry facial expressions.

The significant predictors in the model of angry matching were, age, and LQ2 – LQ1. This was found to vary as a function of age group (the interaction between lateralisation difference for anger processing and age group was significant predictor). This analysis shows that the laterality quotients' difference between time 1 and time 2 of testing was a significant predictor showing a positive relationship whereby the more right hemisphere lateralised a child was at time 2 the more accurately the child performed the task at time 2. The significant interaction of change of laterality and age group was broken down by comparing the correlations between anger matching and emotion lateralisation change across the three age groups. There was a positive correlation which approached significance for the 6 year olds, r (46) = .222, p = .069, but not for the 8 year olds, r (43) = -.075, p = .316, or the 10 year olds, r (57) = -.186, p = .083.

	Performance time 2	age	Performance time 1	Laterality time 1	Laterality time2-time1
Performance time 2		0.231**	0.161	0.003	-0.032
age			0.215**	0.076	-0.122
Performance time 1				0.111	-0.14
Laterality time 1					-0.465**
Laterality time2-time1					

Table 4. 18. Zero-order correlations between behavioural and neuropsychological measures (= p<.010).**

Model		Beta	t	p.
1	**age**	.207	2.480	**.014**
	sex	.010	.120	.903
	Performance time 1	.115	1.370	.170
2	age	.168	1.640	.102
	sex	-.093	-.910	.361
	Performance time 1	.128	1.510	.132
	Laterality time 1	-.723	-1.260	.209
	Laterality time 1 x age	.270	.570	.565
	Laterality time 1 x sex	.459	1.650	.099
3	**age**	.261	2.400	**.017**
	sex	-.080	-.730	.461
	Performance time 1	.130	1.550	.124
	Laterality time 1	-.127	-.200	.837
	Laterality time 1 x age	-.357	-.660	.507
	Laterality time 1 x sex	0.461	1.500	.134
	Laterality Difference	1.293	2.270	**.024**
	Laterality Difference x age	-1.227	-2.410	**.017**
	Laterality Difference x sex	-.095	-.322	.748

Table 4. 19. Anger Matching: Predictors entered in the models.

4.1.3 Discussion

The goals of this study were to assess the development of different facial emotions recognition skills, and development of hemispheric asymmetry. Most importantly, the main aim of the study was to explore the relationship between the development of right hemisphere processing for emotions and facial emotion recognition skills; specifically whether changes in strength of emotion lateralisation for emotion processing can predict developmental changes in emotion recognition. In summary, it was found that children who had stronger right hemisphere lateralisation (more positive LQs) or developed stronger right hemisphere lateralisation for emotion processing over the year (had greater LQ2 – LQ1 difference) was more accurate in facial emotion discrimination and matching tasks, respectively. A sex difference was identified in the matching of sad faces and laterality development: laterality development significantly predicted boys' accuracy in matching sad faces. Findings are discussed below, first to demonstrate how children's development over the period of one year on emotion recognition accuracy is related to findings from previous work, and second to discuss how strength of lateralisation for emotion processing may explain some of the variability in children's increasing emotion recognition skills.

Emotion discrimination and emotion matching skills

Our findings for the development of the emotion recognition skills are overall, in line with previous research (Kolb et al., 1992; De Sonneville et al., 2002; Tottenham et al., 2011; Johnston et al., 2011) whereby using accuracy measures facial expression processing skills improve with increasing age. In line with previous research, it was found in this thesis that the 6-year-olds were less accurate than both older groups of children (8-year- olds and 10-year-olds) in all three tasks (the emotion discrimination, emotion matching and identity matching tasks). In the emotion matching task girls performed more accurately than boys. Interestingly, significant improvement in accuracy between time 1 and time 2 of testing varied with the emotion and the task at hand. For instance, in the emotion matching task, the accuracy matching of happy, sad and angry faces significantly improved at time 2 relative to time 1. In the identity matching task, children were significantly improved (they were more accurate) by being better at inhibiting sad emotional information and surprise at time 2 than at time 1 in that they were more accurate at matching identity. This shows that different emotional processing abilities recruited by different tasks develop at different rates in the three age groups and for different emotions. The three tasks will be discussed separately below.

Emotion discrimination requires that children compare and match configural characteristics of a facial expression with the internal representation of a target emotion employing configural processing (see chapter 2). The present findings show first, that although accuracy levels were generally high (above

90%), the development of emotion representations' refinement is still under way as shown by the main effect of age. Second, of the six facial expressions the one with the most poorly defined representation is that of fear. The results are partly in line with results found in similar studies (Bullock & Russell, 1985; Durand et al., 2007; Gagnon, Gosselin, Hudon-ven der Buhs, Larocque, & Milliard, 2010; Vicary, Reilly, Pasqualetti, Vizzotto, & Caltagirone, 2000). These studies report development in discriminating emotions across middle childhood fear being discriminated later than other emotions and before the disgust. Gagnon et al. (2010) postulated the incremental conceptual differentiation hypothesis whereby the concept of fear gradually emerges from previously acquired concepts of happiness, anger and sadness (see chapter 1).

Emotion matching involves less deep processing: comparing and matching facial features employs an analytic encoding of faces (Karayanidis et al., 2009) and it is thought to impose high demands in children (De Sonneville et al., 2002). Our results show not only that the process involved in emotion matching improve significantly with age but also suggest better visual discrimination for the emotions of happy, sad and angry facial expressions with age possibly because of reduced ambiguity or sharing of the facial features with other expressions over time or because of the ongoing refinement of the visual system which might be ongoing even in later childhood (Gagnon et al. 2010). This pattern of development is similar to that reported by De Sonnevillle, et al. (2002). Contrary to De Sonneville et al., however, we found sex differences in emotion matching whereby girls performed more accurately than boys in the emotion matching task.

In emotion matching task sex differences were observed: girls (in the 6- and 8-years groups) were better than boys in matching facial expressions. Sex differences in facial emotion processing skills in children have not been extensively investigated. Thus far, sex differences in emotion recognition in children have been found but in an inconsistent way (Gross & Balliff, 1991), and McClure (2000), in a meta-analysis of affective studies with children, found only a small female advantage in different facial expression recognition tasks. Different explanations have been proposed to account for reported sex differences: some researchers have pointed towards the anatomical differences and different rates of maturation of neurological structures responsible for emotion processing, such as amygdalae and prefrontal cortex. For example women have a larger orbital frontal lobe (Gur, Gunning-Dixon, Bilker, & Gur, (2002), a brain area which is important for sending input to the amygdala and for inhibition of aggressive behaviour. Other researchers have suggested that early experience and socialisation practices are likely to interact with neurological structures and processes to determine the developmental course of facial emotion processing (Nelson & de Haan, 1997). Why the present study found sex differences only in accuracy in the emotion matching task and not the identity matching task which taps into subcortical neural processes requires further investigation.

Identity matching is an implicit emotion processing task and it involves ignoring the emotive information and focusing on identity. Herba et al., (2006), as discussed in chapter 2, suggested that the distracting effect of emotion on an identity matching task is an index of neural correlates of emotion processing. Performance, therefore, depends on the quality of internal emotion representations and emotion decoding skills. (from faces, configural or analytical face processing skill) as well as the development and maturation of subcortical emotion specific structures such as amygdala and prefrontal cortex (De Sonneville et al., 2002; Gagnon et al., 2010; Herba et al., 2006; Lobaugh; Gibson, & Taylor, 2006). Results of the identity matching task possibly reflect this maturation: emotion affected the identity matching but with development there is a decrease in the distraction of emotion on identity matching. Sad and surprised facial expressions were the emotions that children could not ignore at time 1 of testing in the identity matching task whilst one year later the processing of these two emotions improved. Our findings reflect this on-going maturation between 5-10 years of age, which is consistent with findings of Herba et al. (2006) in a similar task.

Linking the laterality for emotion processing and emotion recognition

The findings of the established laterality replicate previous research (e.g., Workman et al., 2006) whereby all three age groups were right hemisphere lateralised for processing happy sad and angry facial expressions except the 6-year-old children who were bilateral for processing sad expressions at time 1 of testing.

More specifically, our finding replicates finding of Workman et al. (2006) whereby laterality for sad facial expressions in their youngest group was significantly different from that of 10 year olds at time 1 of testing (less right hemisphere dominant). Our finding about the accuracy difference between the two visual fields (LVF – RVF) is comparable to the finding of Workman et al. (2006) as far as the laterality for anger processing is concerned: the right hemisphere superiority for angry processing emerged at the age of 9 years.

The main aim of this study was to explore how children’s developing lateralisation for emotion processing was predictive of their ability to accurately recognise facial emotions. It was found that the role of laterality varied depending on the task being assessed. For instance for the emotion discrimination task the degree of lateralisation at time 1 significantly predicted children’s accuracy, while for emotion matching it was the change in lateralisation for emotion processing from time 1 to 2 that predicted task performance. We know that children’s performance increased over the one year for both emotion tasks; importantly though, for the emotion discrimination at both time points proficiency was quite high (over 90%) and the effect was of medium size (.07) while for the emotion matching task there was greater differentiation (see Figure 4.10) with a large effect (.22). This may indicate that when children are becoming proficient in a task the established degree of laterality is more important rather than the developmental changes of laterality across the year.

However, when task performance is continuing to develop (as with the emotion matching task) developmental changes in strength of lateralisation are important predictors of greater performance changes. Consistent with this idea, Watling and Bourne (2013) found that only 6 year olds who were more strongly right hemisphere lateralised were more accurate in discriminating happiness, not the 8 or 10-year-olds when it would be likely laterality for emotion processing and emotion discrimination would be already established: happiness recognition is an already developed skill and is already lateralised at the age of 5-6 (Workman et al., 2006). Furthermore, Workman et al. (2006) found that degree of laterality was important for better performance in the emotion in the eyes and situational cartoon tests and this was found only for 5-6 year olds. If we take into account the findings by Castro-Schilo and Kee (2010) who reported that established emotional intelligence (EI) ability was associated with stronger right hemisphere dominance, then we can speculate that when emotion processing skills reach proficiency then the degree of established right hemisphere advantage becomes significant (Watling and Bourne, 2013, under review). The finding in this thesis seems to extend the previously found relationship between greater right hemispheric advantage with greater accuracy in emotion recognition skills (Watling and Bourne, 2007, 2013, under review; Workman et al., 2006) as it shows that not only age and established hemispheric asymmetry, but also the development of this asymmetry is important for better performance in difficult tasks.

Another interesting finding was that laterality development was significantly associated only with the emotion processing task, not the identity matching task where the participant was asked to focus on identity and not emotions (emotions were irrelevant to the task). Often the identity matching task is used as an implicit measure of emotion recognition (shows how emotional information can interfere with facial processing). However, this does indicate that hemispheric laterality for facial emotion processing is more specific to performance on emotion recognition tasks than to other tasks that include emotional information but that do not ask participants to focus on the emotional content (i.e., the identity matching task).

When looking at the degree of laterality for the emotions of happiness sadness and anger and the processing performance of these emotions in the matching task, we found that, laterality change was predictive of more accurate matching of sad facial expressions and angry facial expressions only for boys who performed worse than girls in the sad matching task. Thus, the relationship between lateralisation development for processing emotions and facial emotion recognition skills is specific to boys not the girls. Boys were less accurate than girls and this is where laterality development was most likely reflected in the relationship with enhanced performance at time 2. Whilst no previous study has explored development of hemispheric asymmetry and performance, the sex difference found is consistent with previous research, which reported sex differences in the hemispheric asymmetry in adults. Bourne (2005), for instance, found that males and females had a right hemisphere advantage when perceiving happy facial expression from chimeric faces, but males were more strongly lateralised than females who were more bilateral. More recently Lin (2009) reported sex differences in brain responses to fearful and sad faces, where females had significantly more activation than males in amygdala while viewing sad faces versus neutral and this region was functionally connected with regions at both hemispheres. Males had greater activation in parietal lobes to fearful than neutral faces which were functionally connected with right hemisphere regions. It seems therefore, that in females and males facial emotion processing is organised in different ways. Females appeared to have bilaterally distributed facial emotion processing mechanisms. One could speculate that because of the later females are generally faster than males when they accurately identify facial emotions (Bourne, 2005; Rahman et al, 2004; Nowicki and Hartigan 1988). Whilst we did not find any sex differences in children's hemispheric asymmetry, it seems that greater development of the laterality toward the right hemisphere is important for greater emotion recognition skills for boys. Dominance of the right hemisphere and its resources in boys perhaps is a compensatory mechanism for emotion recognition differences between males and females.

Whilst happiness recognition is an already developed skill and is already lateralised at the age of 5-6, sad and angry recognition and their laterality are still developing (e.g., Workman et al., 2006). The latter shows that the development of the hemispheric asymmetry for emotions whose recognition skills are still developing predicts changes in the processing of this emotion as is reflected in the analysis. This finding also fits well with the corpus callosum research by Hagelthorn et al. (2000, in chapter 1), which found that maturation and myelination of the CC was associated with increased laterality (and decreased interhemispheric transfer time which in this study we did not measure, but it would be interesting to do in the future). It would be important to see whether laterality development is important for the processing of the basic emotions which this study did not look at.

In summary, study 3 explored longitudinal links with how facial emotion recognition skills may be predicted from changes in hemispheric lateralisation. In this there was evidence that laterality for emotion processing was related to performance. Importantly, these links were not dependent on the age of the child, but there were some links with the sex of the child. Additionally, the role of laterality was different dependent on the emotion recognition task and was not related to the performance on the identity matching task. When the task was more difficult there were greater developmental differences between time 1 and 2 and it was then when the level of increased strength of laterality over the year predicted developmental improvements in task accuracy; however, when the task was not as difficult (smaller developmental differences between time 1 and 2), it was the strength of laterality at time 1 that was a stronger predictor of developmental improvements in accuracy rather than the developmental changes in strength of laterality for facial emotion processing. Importantly, this work was with emotions that were all presented at 100% of intensity, it would be important to explore links with laterality when emotions are presented at lower intensity (thereby making the tasks more difficult).

4.2 Study 4

This study will investigate children's sensitivity to the recognition of emotion at differing intensities and whether it is differentially affected by processing in the left or right hemisphere. As seen in chapter 1, the ability to recognise facial emotional information emerges gradually with development. Not only improves with age but also varies with emotion, happiness reaching adult levels of accuracy earliest, followed by sad or angry expressions, then by surprise or fear (Herba & Phillips, 2004; chapter 1). The evidence has been consistent across developmental studies which, however, used facial expressions with 100% intensity of emotion.

Whilst it is important to understand the development of intense emotional processing skills, children mostly in their everyday life see lower intensity facial expressions than full intensity expressions. Therefore, it is important to explore children's ability to recognize facial expressions of lower intensity and understand the subtleties of emotional processing. Studies which have investigated the effect of intensity in facial emotion recognition skills are very few. Initially researchers explored sensitivity to lower intensities of fear and sadness in children who were at risk of psychiatric disorders. In one of these studies Blair et al. (2001) found that children with tendencies to psychopathy needed significantly greater intensity to correctly identify sadness. Most recently, Herba et al. (2006) investigated the effect of different emotion intensities on children's emotional matching skills, from 4- to 15-years- old. They found first, that emotion recognition accuracy improved from 50% of intensity to the higher intensities (75% and 100%) compared to 25% of intensity. Second, they found that the ability to recognise lower intensities of emotional expressions differed with emotion and age. Along similar lines Thomas et al. (2007) compared older children's (7-13 year olds), and adolescents' (14-18 year olds) sensitivity to fearful and angry expressions of different intensities to sensitivity of adults. Sensitivity to fear increased linearly across the three age groups. This was not the case for anger which only increased markedly from adolescence to adulthood. Additionally, Montirosso et al. (2010) found an increasing ability to recognise lower intensities with increasing age and that accuracy varied with emotions. Happiness was unaffected by intensity. Whilst negative emotions were well recognized when they were expressed at 100% intensity, at the lower intensity (35 %) there was greater accuracy for fear compared with sadness and anger. With regard to age and intensity, Montirosso et al. found that increasing age was associated with more accurate recognition at lower intensity levels. The results suggest a slight improvement in recognition at low and medium intensities (i.e., 35 and 50 %) only in their adolescent group (13- to 15-year-old and 16- to 18-year-old groups, and none in the younger children (7-9 year olds). Thus, accuracy at lower intensity expressions developed until early adolescence, probably due to a greater perceptual ability in detecting subtle changes in facial emotion.

Gao et al. (2009, 2010) confirmed different developmental patterns for different expressions. From the age of 5 years children were as sensitive as adults to recognise happiness at different intensities. For sadness, 5 years old children had adult-like thresholds to detect sad facial expressions, but even at 10 years of age, they were more likely to falsely judge sad as fearful. For fear, children's detection thresholds were adult-like at 10 years of age, and 5 to 7 year-olds often confused fear with sadness. Anger had slow developmental trajectories with even 10 year olds misjudging low and middle intensity levels of angry as neutral. For surprise 5 to 7 year olds compared to adults were more likely to misidentify surprise as fear and happiness but equally likely to misidentify fearful expressions as surprised.

What the above studies showed is that finer aspects of emotional processing skills unfold with development and this development is indicated by better facial expressions recognition performance at lower intensities with age. The aims of this study were primarily to investigate how children's recognition of emotion at differing intensities may be affected by their tendency to process emotion in the right or left hemisphere. While the work thus far in this thesis has explored laterality for emotion processing with the Chimeric Faces Test, this study uses an alternative measure of laterality, the Divided Visual Field (DVF) paradigm. Using the DVF in this study, which is a paradigm that is extensively used in adult hemispheric asymmetry research, will complement the findings of the longitudinal study with regard to assessing laterality across different age groups. In particular, this study sets out to examine the subtleties of emotion processing by using faces of different intensities. It also aims to explore links between hemispheric processing of facial emotion with better performance in facial emotion recognition tasks using facial emotions with different intensities. This is a cross-sectional design to examine the effect of age and intensities on facial expression processing development and examined children's emotion-processing using a DVF task, an emotion recognition task and an emotion matching task. Given the findings in Study 3, an identity matching task was not used, and a modified emotion discrimination task was used to increase the difficulty.

The same five emotions used in the previous longitudinal study 3 (section 4.1) were used here (happy, sad, angry, fear, and surprise) but each on the emotions was displayed at three intensities (30%, 60% and 90%). Importantly, these three intensity levels were chosen as a result of the aforementioned review (see Section 4.2), which suggested that children's ability to recognise facial expressions at different intensities develops with age. Children as young as 5 years old find it difficult to recognise facial expressions at 25% of intensity; their ability to recognise facial expressions at lower intensities improves from 50% to 75% over the middle childhood years. It was anticipated that 5-year-olds recognition of emotion at 30% would be possible, although there would developmental changes in accuracy.

As with other work on emotion recognition, it is expected that the older children will have greater accuracy with age and at each intensity level, but with distinct developmental patterns for each of the five emotions. Further, it was expected differential sensitivity scores for different emotions and intensities depending on the visual field of stimulus presentation. Importantly, in line with the longitudinal work, it was expected that children who had better recognition of facial expressions of emotion presented in the left visual field (LVF) in comparison to the right visual field (RVF) would have better emotion recognition skills in the emotion recognition task (ERT).

4.2.1 Method

Participants

Participants were recruited from a local primary school, in a middle- class neighbourhood in Surrey. A total of 82 children (45 boys, 37 girls) participated in the study. There were 27, 5-year-olds (M=5.6, SD=.32; range

5.0 to 6.18; 20 boys), 28, 7-year-olds (M=7.7, SD=.30; range 7.24 to 8.20 years; 14 boys), and 27, 9-year-olds (M=9.8, SD=.37; range 9.25 to 10.14 years old; 11 boys). All children were right handed and typically developing.

The Head Teacher preferred to use an opt-out form for consent; parents were sent information regarding the study and asked to return the form to the class teacher if they wished for their child not to participate.

The study was approved by the Royal Holloway, Department of Psychology, ethics committee.

Participants who gave verbal assent to participate were asked individually to sign their name on the top half of a piece of paper and then were asked to pick up the child scissors and to cut the paper in half. The researcher recorded whether they used their right or left hand to write their name, use the scissors. Additionally, once the children were seated at the computer and used the mouse the researcher noted which hand (left or right) the child used to move the mouse. If a child used the left hand in any of the three measures they participated in the study but their data were excluded from the analysis. These three tasks were used to assess handedness. If a child used their left hand for any of the three tasks (writing their name, cutting the papers, clicking the mouse) their results were excluded additional analyses. None of the 82 children were excluded from analysis because of their handedness.

Material

Three tasks were used in this study: An Emotion Recognition task, and an explicit emotion-matching task. Also, a Divided Visual Field task was used as a measure of laterality. Two of these tasks were forced choice emotion identification tasks (the Divided Visual Field task and Emotion Recognition task). The stimuli used were the same black and white photographs of NIMH (National Institute of Mental Health) pictures, previously validated (chapter 2) and used in all studies in this project. The faces in this study displayed five basic emotional facial expressions (happy, sad, fearful, angry and surprised) and neutral. All faces were posed in full frontal orientation. The stimuli were framed with a black oval mask to remove additional features such as hair and ears, thereby allowing children to focus on the internal features of the face and emotion. Prototypical expressions of all five emotions (at 100% of intensity) were morphed, using Abrosoft FantaMorph 4.2 software, with neutral expressions of the same actor to create three intensity levels for each emotion (30%, 60% and 90%). Therefore, for each actor there were a total of 16 images (3 for each emotion and the neutral expression). One example from each of the emotions continua is shown in Figure 4.14.

The tasks were randomly presented to participants on a Dell inspiron 15 inch laptop computer using Runtime Revolution 3.0 software that allowed for presentation of stimuli and verbal components (i.e., instructions) via a set of headphones for each task. Children’s responses were recorded by the software as they clicked on their responses.

Figure 4. 14. Examples of morphs continua used. From top to bottom: happy, sad, angry, scared and surprised; from left to right: 30%, 60%, and 90%.

Design and Procedure

Participants were seen in groups of three in a quiet room of the school. All children were informed about the study, and were given the opportunity to ask questions, as well as to opt out of the study. Children's handedness was assessed, as outlined in the participants' information. Participants were also required to rest their chin on a chin rest that was adjusted to about 45 cm from the screen. This was necessary in order to ensure that the children's head is at a constant distance away from the monitor (Bourne, 2006).and were asked to put on the headphones

Children performed three tasks: i) A divided visual field task (DVF), ii) an emotion recognition task and iii) an emotion matching task.

The tasks were randomly presented to participants on a Dell Inspiron 15 inch laptop computer or a 15 inch desktop in the ICT suite of the school. Runtime Revolution 3.0 software allowed for simultaneous presentation of stimuli and verbal components (e.g., instructions) for each task via a set of headphones.

The order of the tasks for each child and the trials in each task were randomly assigned through the Revolution Studio programme.

Divided Visual Field task (DVF task): The Divided Visual Field methodology is described in detail in section 2.2.3. For this task, two male and two female image sets were used. Each image set included three intensity levels (30%, 60% and 90%) for each emotion and the neutral face. In total, for each emotion there were 12 images. All images were of the same size, subtended approximately 8.5° horizontally and 12° vertically. Participants' emotion recognition was assessed within blocks which included 22 trials (12 target trials, and 10 non-target trials) with presentation randomised by the computer programme. Within each block, for both the target and non-target trials, half of the trials had the target image presented in the left visual field and half in the right (counterbalancing for percentage of emotion shown). The computer program also randomly selected two trials from each of the non-target emotions (one for presentation in the RVF and one for presentation in the LVF).

At the beginning of each block the participants were instructed that a face would appear on the left or the right side of the fixation and they had to respond with a button press on the response card to indicate whether or not the target emotion was present. (this instruction remained consisted for each participant across all blocks of the task).

Within each block, each trial began with a fixation cross presented at the centre of the screen for 500ms, followed by a small cartoon (for attention catching and fixation control, chapter 2), which was presented for 250ms. The cartoon disappeared and a face was presented for 250ms, with the inside edge 2.5° from central fixation, either on the left or the right of the fixation cross. In each emotion block there were 6 faces of the target emotion presented on the left and right visual field, expressing the emotion at the three intensities (30%, 60% and 90%). One face of each of the other non-target emotions was also presented to the two visual fields expressing the emotion at the three levels of intensity. In total there were 22 trials in each block. After the face went away a backward mask (blank screen) followed, and the question whether the face was “Happy” or “Not Happy”, “Sad” or “Not Sad” etc. appeared which remained on the screen until a response was made (Figure 4.15).

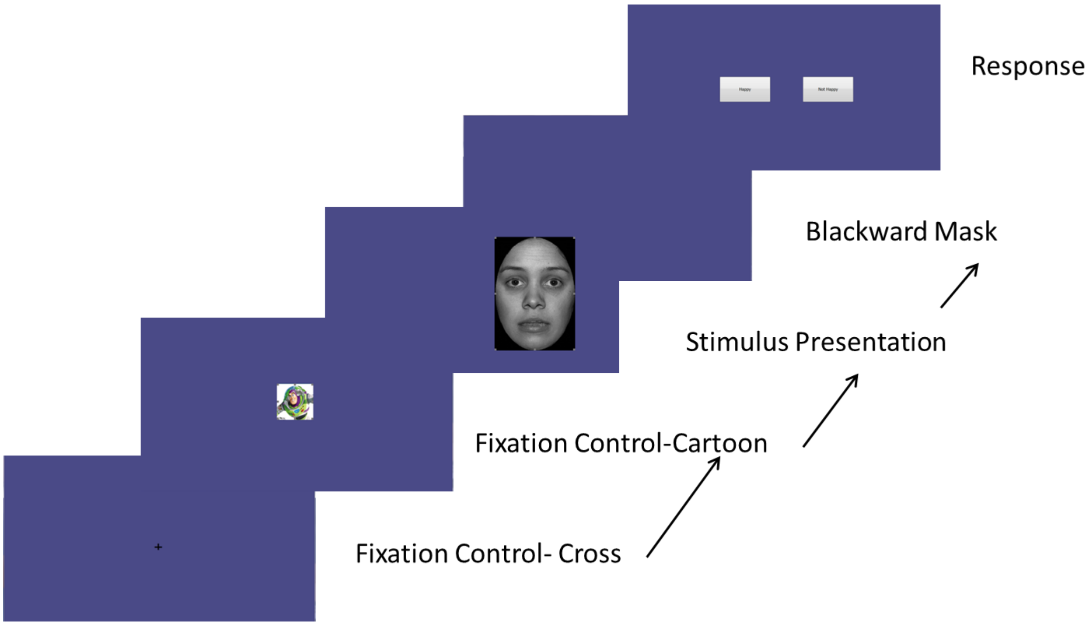

Figure 4. 15. DVF: Protocol of events in each trial of the task.

When the stimuli were presented, the cursor was not visible, when the question appeared the cursor was positioned at the bottom centre of the screen. The task started with an instruction page, where children listened to the instructions through the headphones. Children were instructed to look only at the fixation cross and the cartoon at all times, without moving their eyes, and click on the chosen answer to the question (e.g. “Happy” or “Not Happy”).

When they were ready they would click an arrow for the task to begin. Before beginning children had five practice trials where feedback was given to them through the headphones only for wrong responses. (“Are you sure you wanted to press that button? Try again!”). When children responded correctly on the practice trial the programme would automatically move to the next practice trial. After the practice trials a secondary instruction screen came up that reminded participants what they were required to do, including that they should look at the fixation cross at all times. When children were ready they would press a ‘Begin’ button.

A trial ended when the participant made a response (the faces were presented until a response was made). Participants responded by clicking on the “Happy” or “Not Happy”, “Sad” or “Not Sad” etc. button at the response card. Once they responded the card would automatically change to another trial.

Children received a score from 1 to 0. They would get a score of 1 if they got a hit and correct rejections (clicked the “emotion” button when there was an emotion, or when clicked the “not emotion” when there was not the target emotion) or 0 if they got a miss, and false alarms (clicked the “not emotional” when there was the emotion, or clicked “emotion” when there was not the target emotion).

Emotion Recognition Task: (ERT) The task is described in section 2.1. This task was administered in the same way as in the previous DVF task above. A fixation cross was presented at the centre of the screen for 500ms which was followed by a face which was presented for 1500ms, at the centre of the screen. After the face went away a question whether the face was happy or not happy, sad or not sad etc. appeared which remained on the screen until a response was made. As in the previous DVF task, all faces were of the same size, subtending approximately 8.5o horizontally and 12o vertically. Presentation of the faces was counterbalanced and randomized across the experiment and between participants. The stimuli were presented in blocks one for each emotion. In each emotion block there were 6 faces of the target emotion presented (one female, one male and each in three emotion intensities) at the centre of the screen. Two faces of each of the other non-target emotions were also presented in each block. In total there were 16 trials in each block.

After the face went away, a blank screen appeared very briefly as a backward mask, and the a question whether the face was “Happy” or “Not Happy”, “Sad” or “Not Sad” etc. appeared which remained on the screen until a response was made (Figure 4.16). During the stimulus presentation, the cursor was not visible, when the question appeared the cursor was positioned at the bottom centre of the screen. The task started with an instruction which children listened through the headphones. When they were ready they would click an arrow for the task to begin Before beginning children had five practice trials where feedback was given to them through the headphones for wrong responses only ("Are you sure you wanted to press that button? Try again!"). When children responded correctly on the practice trial the programme would automatically move to the next practice trial. After the practice trials a secondary instruction screen came up that reminded participants what they were required to do, including that they should look at the fixation cross at all times. When children were ready they would press the 'Begin' button. The trial ended when the participant made a response (the faces were presented until a response was made). Participants responded by clicking on the "Happy" or "Not Happy", "Sad" or "Not Sad" etc. button at the response card. Once they responded the card would automatically change to another trial.

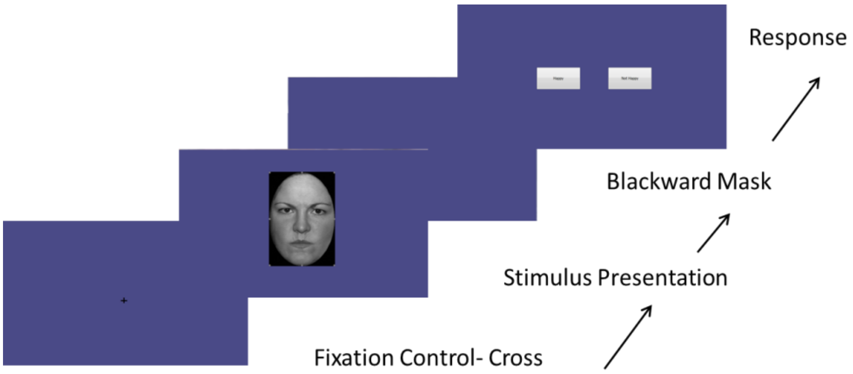

Figure 4. 16. Emotion recognition task (ERT): Protocol of events in each trial.

Accuracy measures were recorded by the Runtime Revolution programme. From the scores Hits, False Alarms, Misses and Correct Rejections were calculated. Children received a score from 1 to 0. They would get a score of 1 if they got a hit and correct rejections (clicked the “emotion” button when there was an emotion, or when clicked the “not emotion” when there was not the target emotion) or 0 if they got a miss, and false alarms (clicked the “not emotional” when there was the emotion, or clicked “emotion” when there was not the target emotion.

Explicit emotion-matching task: The task is described in section 2.1. The task was adapted from Herba et al., (2006) and Bruce et al. (2000). Three faces were presented on the screen. One at the top centre was the target stimulus and two faces at the bottom left and right of the screen were the choice stimuli. Participants were asked to match the emotion of a target stimulus with one of two choice stimuli (Figure 4.17). The target stimulus was of the same sex as the two choice stimuli. In half of the trials the choice stimuli were of the same identity as the target stimulus and in half of the trials the three stimuli were of a different identity. Also the target stimulus in all trials was of the same gender as the two choice stimuli (Bruce et al., 2000; De Sonneville et al., 2002). The target and one of the choice stimuli were of the same emotion but of different intensity of this emotion. The other choice stimulus was neutral. There were a total of 60 trials. In the first 30, the faces were of a female posing five emotions in the three intensities, and 30 were male identities, posing five expressions in three intensities. Before beginning children had five practice trials where feedback was given only for wrong responses through the headphones ("Are you sure you wanted to press that button? Try again!"). When children responded correctly on the practice trial the programme would automatically move to the next practice trial. After the practice trials a secondary instruction screen came up that reminded participants what they were required to do. When children were ready they would press the 'Begin' button. Each trial started with the children hearing through the headphones the instructions for the task. The trial ended when the participant made a response (the faces were presented until a response was made). Participants responded by clicking on the face on their right side or by clicking on the face on their left side. Once they responded the card would automatically change to another trial. Accuracy recorded by the Runtime Revolution programme. Children received a score from 0 to 1. They received 1 if they clicked the correct response or 0 if they clicked the wrong response. Scores were subtotalled for each emotion, with scores ranging from 0 to 6, and a total emotion matching score ranging from 0 to 60 and percentage correct was calculated.

Figure 4. 17. Example of presentation trial for the emotion-matching task (target emotion at the top).

4.2.2 Results

For the Emotion Matching Task the percentage correct were computed for each emotion, in three intensities and were analysed. Means (SE) for the Emotion Matching Task percentage correct are presented in table 4.20 below.

Emotion Matching Task

Emotion	5-6 year olds	7-8 year olds	9-10 year olds
	N=27	N=28	N=27
Happy	79.8(3.03)	77.5(2.91)	89.4(2.91)
Sad	55.9(2.92)	62.4(2.81)	64.7(2.81)
Angry	68(3.28)	76.2(3.16)	78.2(3.16)
Fear	59.7(2.94)	55.1(2.82)	56.4(2.82)
Surprise	71.5(3.18)	74(3.06)	76.2(3.06)

Table 4. 20. Explicit Emotion Matching Task: Means (standard errors) for percentage correct for each age group and emotion.

For the Divided Visual Field and the Emotion Recognition tasks, because participants had to make a binary forced choice decision, emotional / not emotional, Signal Detection Theory (SDT) analysis was applied. Following the data collection the responses were categorised as hits (e.g., participants judged that a happy face was happy), misses (e.g., participants judged that a happy face was not happy), false alarms (e.g., participants judged that a face was happy when it was not happy), and correct rejections (e.g., participants judged that a face was not happy when it was not happy). Hits and false alarm rates were used to calculate the signal detection parameters: sensitivity (*d′*: discriminability) and criterion (C: bias); Green and Swets, 1966). The underlying model of SDT consists of two normal distributions: One representing a signal (target present) and the other one representing the "noise" (target absent). How well a person can discriminate between Signal Present and Signal Absent trials is represented by the difference between the means of the two distributions, d', which is a measure of sensitivity-accuracy. The larger the d' value, the more accurate the performance was. The willingness of the person to say 'Signal Present' in response to an ambiguous stimulus is represented by the criterion, C, which is a measure of response bias. A “low” criterion means that the participants respond “yes” to almost everything (have a very high % correct – HIT rate, but a lot of False Alarms). A high criterion indicates that the participants respond “no” to almost everything.

Means (SE) for DVF task for each age group and each emotion are presented in figures 4.18, 4.19 and 4.20. Means (SE) for the ERT are presented in table 4.21 below. Consistent with the focus of the thesis which is laterality and facial emotion recognition in the DVF task we are looking at the emotions separately, in order to see visual field biases for different emotions whilst in the ERT we put the emotions in one analysis.

Emotion Recognition Task: Accuracy (d’ measure)

Emotion	5-6 year olds N=27	7-8 year olds N=28	9-10 year olds N=27
Happy			
30%	.050(.128)	.137(.128)	683 (.125)
60%	1.718(.162)	1.275(.162)	1.591(.158)
90%	1.518(.143)	1.466(.143)	1.523(.139)
Sad			
30%	.217(.183)	.847(.183)	.843(.179)
60%	.929(.218)	.883(.218)	1.135(.213)
90%	.971(.189)	1.172(.189)	1.322(.185)
Angry			
30%	.324(.154)	.491(.154)	.251(.150)
60%	1.462(.170)	1.442(.170)	1.572(.166)
90%	1.529(.155)	1.606(.155)	1.760(.151)
Fear			
30%	.751(.173)	.760(.173)	.938(.169)
60%	1.043(.156)	1.358(.156)	1.599(.153)
90%	.948(.187)	1.412(.187)	1.405(.183)
Surprised			
30%	.648(.203)	1.187(.203)	.869(.199)
60%	.910(.154)	1.301(.154)	1.382(.150)
90%	.941(.164)	1.164(.164)	1.544(.160)

Table 4. 21 Emotion Recognition Task (ERT): Means (standard errors) of d' measure of accuracy for hits (SE) for each age-group, emotion and intensity.

Divided Visual Field: d’, c scores and false alarm rates were computed for each emotion, in three intensities and in the visual field of stimuli presentation (left or right). The d’ scores were calculated separately for each age group and each emotion (see figures 4.18, 4.19 and 4.20). Also, the means (SE) for the C measure of bias across emotions and for both left and right visual fields are shown in table 4.22. C has a positive value, which is an indicator of a bias of the children to respond that the face was “emotional” on many of the trials, and therefore have more false alarms than hits. Means (SE) for the false alarm rate across emotions are shown in table 4.23

DVF task: C’ measure of bias’

Age	Means (SE)					
	C_30% *LVF*	*C_30%* *RVF*	*C_60%* *LVF*	*C_60%* *RVF*	*C_90%* *LVF*	*C_90%* *RVF*
5 years	*.117 (.060)*	*.524 (.089)*	*.249 (.062)*	*.613 (.091)*	*.520 (100)*	*.559 (.094)*
7 years	*.318 (.060)*	*.677 (.089)*	*.293 (.062)*	*.885 (.091)*	*.698 (100)*	*.853 (.094)*
9 years	*.396 (.057)*	*1.044(.085)*	*.311 (.060)*	*.948 (.088)*	*.823 (.096)*	*1.063 (.090)*

Table 4. 22 DVF: Means (standard errors) for the C measure of bias of the three age groups in three intensities and LVF and RVF fields.

DVF task: False alarm rate

Age	Means (SE)					
	FA_30% LVF	FA_30% RVF	FA_60% LVF	FA_60% RVF	FA_90% LVF	FA_90% RVF
5 years	.436 (.036)	.402 (.039)	.355 (.042)	.349 (.039)	.392 (.045)	.354 (.039)
7 years	.371 (.036)	.362 (.039)	.351 (.042)	.303 (.039)	.364 (.045)	.342 (.039)
9 years	.310 (.035)	.266 (.037)	.327 (.040)	.258 (.038)	.330 (.044	.243 (.037)

Table 4. 23 DVF: Means (standard errors) for the false alarm rate of the three age groups across emotions

A mixed 3 (age group: 5 year olds, 7 year olds and 9 year olds) x 2 (visual field of presentation: LVF, RVF) x 3 (intensity: 30%, 60% and 90%) x 5 (emotion: happy, sad, angry, fearful, surprise) ANOVA was completed separately for each of the 5 emotions on measures of d’, c and false alarm rates.

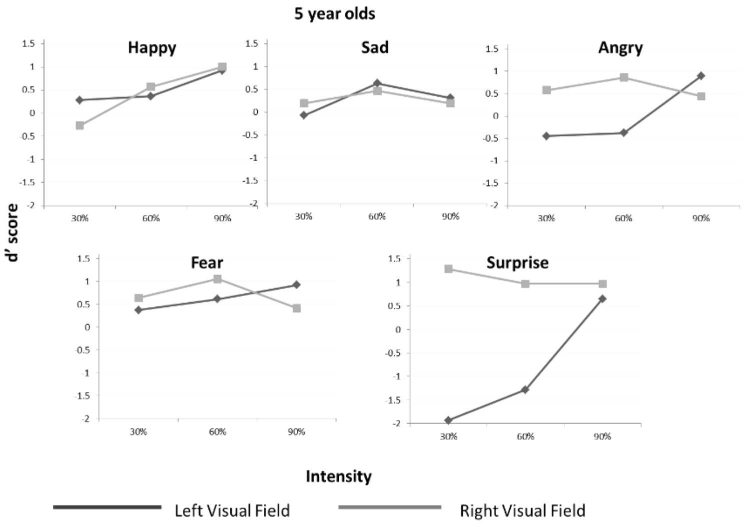

Figure 4. 18. DVF task: d' measure for 5 year olds for all emotions and visual field.

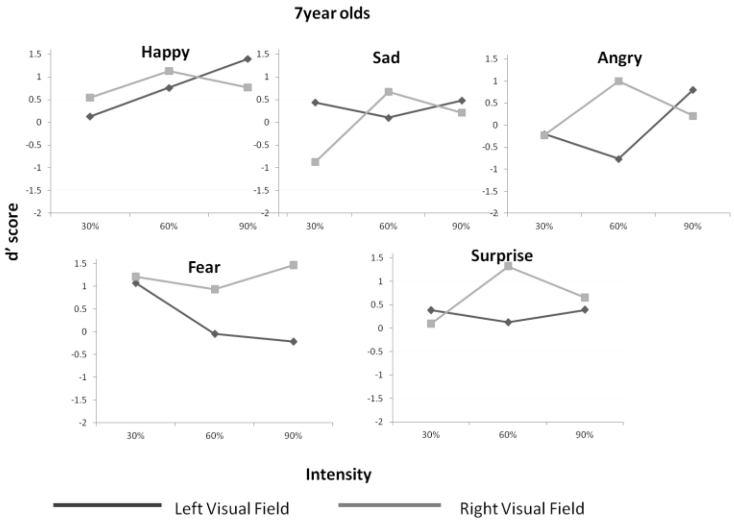

Figure 4. 19. DVF task: d' measure for 7 year olds for all emotions and visual field.

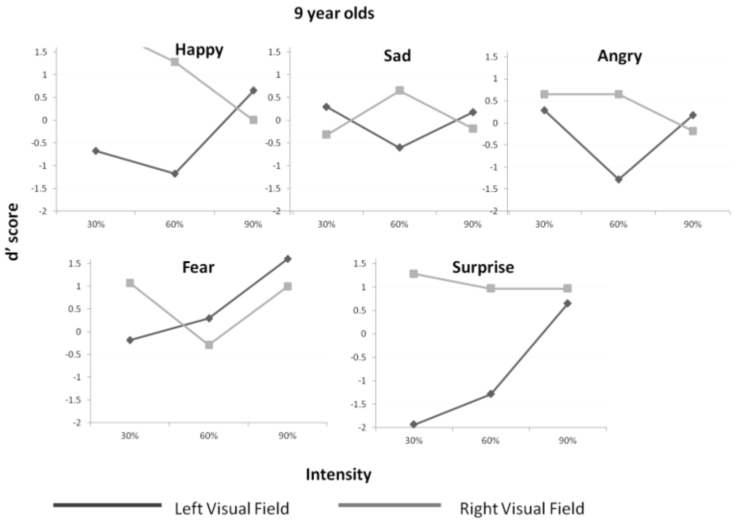

Figure 4. 20. DVF task: 21 d' measure for 9 year olds for all emotions and visual field

Processing happy expressions of emotion: DVF

Analysis of d' measure of accuracy for happy expressions of emotion found a significant main effect of age group, *F* (2, 24) = 4.757, *p* =.018, η^2=.284. Helmert contrasts showed that 5 year olds were significantly less accurate than both the older children combined, p = .015, whereas the 7 year olds were not significantly different to 9 year olds. The main effect of intensity was significant *F* (2, 54) = 18.522, *p* <.001, η^2 = .407. Interestingly, the criterion analysis (C bias) showed a main effect of intensity, *F* (1.663, 104.789) =61.135, *p* <.001, η^2 = .492 and a main effect of visual field of presentation, *F* (1, 63) = 5.680, *p* = .020, η^2 = .083. This was because children, overall, were more accurate with increasing intensity but they were more liberal in their responses to 30% intensity (more likely to say the emotion was "happy") than 60% and 90%. Whilst there was no significant difference in the accuracy between the two visual fields, they were more conservative in their judgment of happy emotion when the faces were presented in the LVF (had a bias to say "not happy"), while when the face was presented in the RVF, they had a bias to say "happy" more. The false alarm analysis revealed a main effect of age group, *F* (2, 28) = 5.065, *p* = .013, η^2 = .266. Helmert contrasts showed that younger children had significantly higher false alarm rate than the two older groups of children combined, (p = .008), indicating that they were more likely to say that an emotion was present when it was not, in other words they were less likely to discriminate.

Processing sad expressions of emotion: DVF

Analysis of d' measure of accuracy for sad expressions of emotion showed that the main effect of age group was not significant, *F* (2, 35) = 2.425, *p* = .103, η^2 =.122. A main effect of intensity was significant, *F* (2, 70) = 8.565, *p* < .001, η^2 = .197.Importantly there was an intensity x visual field x age group interaction which approached significance, *F* (4, 70) = 2.325, *p* = .06, η^2=.117. This was because the interaction between visual field and intensity was only significant for the 9-year-old group, *F* (2, 24) = 4.178, *p* = .028, η^2 = .258. Pairwise comparisons, Bonferroni corrected, showed that the 9-year-old children group: they were significantly more accurate in recognising the 30% intensity expressions when the faces were presented in their LVF, M = .647, SE (.17), than the RVF, M = .055, SE (.24), p = .031. There was no LVF and RVF difference with either 60% or 90% intensity of expression. Criterion analysis showed a significant intensity x visual field interaction, *F* (2,70) = 5.390, *p* = .007, η^2 = .133. Overall children were more conservative (biased to say "not sad") in the judgement of "sad" presented in the RVF than the LVF (p = .003). False alarm analysis showed an intensity x visual field significant interaction, F (2,70) = 3.296, p = .043, η^2 = .086. This was because the 30% intensity had higher false alarm rate than the 90% intensity when the face was presented on the LVF (p = .019). The false alarm rate was also higher when 90% of sadness intensity was presented in the RVF (p = .012).

Processing angry expressions of emotion: DVF

Analysis of d' for angry expressions of emotion showed a significant main effect of age group, *F* (2, 34) = 4.17, *p* = .024, η^2 = .197 whereby the accuracy increased with increasing age. Helmert contrasts showed that 5-year-olds were significantly less accurate than the 7- and 9-year-olds combined, p = .025, whilst the 7-year-olds were not significantly different from the 9-year-olds.Further, there was a significant main effect of intensity, *F* (2, 68) = 44. 72, *p* < .001, η^2 = .554 whereby the 30% intensity of anger was significantly less accurately recognised than the 60% or 90% intensities. Bias analysis showed that children moved from being liberal (saying "angry" most of the time) therefore having more false alarms, to a more conservative judgement with increasing age (saying "not angry" most of the time, but the difference was not significant. The only significant main effect of bias was that of intensity, *F* (1.573, 58.214) = 22.938, *p* < .001, η^2 = .383. Children had a bias to say "angry" at the 30% of intensity, which means they misidentified angry faces as another expression, whilst they became more conservative to respond "not angry" to 60 and 90% of intensity. False alarm analysis did not show any effects.

Processing fearful expressions of emotion: DVF

Fearful Expression

Analysis of d’ for fear showed a significant intensity x visual field x age group interaction F (4, 26) = 2.854, p = .044, η^2 = .305. The interaction intensity x visual field was significant only for the 7-year-old children who were more accurate in recognising the 90% intensity of fear when the face was presented in the RVF, M = 1.215, SE (.40) than the LVF, M = .465, SE(.54) , p = .049 and for the 8-year-old children who were more accurate to identify the 60% intensity of fear when the face was presented in the LVF than the RVF (d’= .463 and .290. respectively, p=.045). There were no effects of the bias. False alarm analysis did not show any significant main effect or interaction.

Processing surprised expressions of emotion: DVF

For Surprise, the d’ analysis revealed a main effect of intensity *F* (2,28) = 12.093, *p* <. 001, η^2=. 463 by which the higher the intensity (90%) the greater the accuracy in recognising surprise. Bias analysis showed a significant main effect of intensity, F (2,28) = 13.196, p < .001 whereby children moved from being liberal (saying “surprised” most of the time) therefore having more false alarms, to a more conservative judgement with increasing intensity (saying “not surprised” most of the time). There were no effects of the false alarm rate.

DVF task summary of findings

DVF summary

Overall, in the DVF task children were more accurate to recognise faces with greater intensity of emotion. So 90% was recognised more accurately than 30% and 60%, and 60% was recognised more accurately than 30%. The accuracy of recognition of emotions for the three age groups differed depending of the emotion. Children became significantly better with age at recognising happy and angry faces at different intensities. Also the visual field of face presentation mattered only for happy, sad, and fearful expressions. All children were more accurate to recognise happy in the LVF than the RVF. Five year-olds and 7-year-old children were better to recognise different intensities of sad expressions when the face was presented in the LVF compared to the RVF, whilst 9-year-olds were better at recognising sad and fear when these were seen in the RVF compared to the LVF.

Further, there was a change in bias with increasing intensity and age. Different patterns of bias were observed with different emotions and visual field of stimulus presentation. Children were more liberal (easier saying “emotion”) in judgement of 30% intensity of angry and surprised faces but became more conservative with 60% and 90% intensities. The judgement of “happy” had the opposite pattern of bias. Children were more conservative in judging 30% of happiness but became increasingly liberal with increasing intensity. Regarding the visual field of stimulus presentation, children were more liberal when they saw a 30% intensity of sad on the LVF than the RVF. The false alarm rate was higher when 30% of sadness was presented in the LVF than RVF. For fear, older children had higher false alarm rates when 60% of fear was presented in the LVF than the RVF.

Emotion Recognition Task (ERT): The d' scores, the C criterion bias and false alarm rate were computed for each emotion, in three intensities. Means (SE) for the ERT task are presented in tables 4.21. Also, the means (SE) for the C measure of bias and false alarm rate for all intensities and across emotions are shown in table 4.24.and 4.25, respectively.

ERT task: C' measure of bias

Age	Means (SE)		
	c_30%	c_60%	c_90%
5 years	.199 (.041)	.606 (.056)	.591 (.051)
7 years	.315 (.041)	.626 (.056)	.682 (.051)
9 years	.361 (.040)	.728 (.055)	.755 (.050)

Table 4.24. ERT: Means (standard errors) of C measure of bias across emotions and for all intensities for the three age groups.

ERT task: False alarm rate

Age	Means (SE)		
	c_30%	c_60%	c_90%
5 years	.343(.029)	.319 (.030)	.341 (.028)
7 years	.310 (.029)	.285 (.030)	.302 (.028)
9 years	.268 (.029)	.264 (.030)	.291 (.050)

Table 4. 25 ERT: Means (standard errors) of false alarm rate across emotions and for all intensities for the three age groups.

The average d' values were analysed with repeated measures ANOVAS. Year group was between-subject factors Emotion (5) and Intensity (3) were the within-subject factors. : d', c scores and false alarm rate were computed for each emotion, in three intensities .A mixed 3 (age group: 5 year olds, 7 year olds and 9 year olds 3 (intensity: 30%, 60% and 90%) x 5 (emotion: happy, sad, angry, fearful, surprise) ANOVA was completed for the 5 emotions on measures of d', c and false alarm rates.

ERT: Accuracy

There was a main effect of age group *F* (2, 61) =3.462, *p*=.038, η^2= .102. Helmert contrasts showed that 5-year-olds were significantly less accurate than both 7- and 9-year-olds combined, p = .027. No significant difference was seen between the 7- and 10- year old groups. The main effect of emotion was significant, *F* (4, 244) =2.757, *p*=.029, η^2= .043. Simple planned contrasts showed that the most accurately recognised was the emotion of anger and the least accurately was the emotion of sadness (p= .018). Further, there was a significant main effect of intensity, *F* (2,122) = 114.198, *p* <.001, η^2 = .652, whereby accuracy improved with increased intensity.

The main effects were qualified by a significant interaction of emotion x intensity, *F* (8,488) =10.954, *p*<.001, η^2 = .152. Simple effects showed that it was significant for all emotions, All F values > 8.21 and all p values < .001, except surprise. Pairwise comparisons showed that for both sadness and fear emotions the recognition accuracy was significantly improved between the 30% and 90% intensity, p<.007. The accuracy recognition for both happy and angry emotions improved significantly between 30% and 60%, p<.001. No significant accuracy differences were seen between the three intensities for surprise.

Analysis of criterion (C bias) revealed a main effect of age group, *F* (2, 61) = 3.462, *p* = .038, η^2 = .102. Helmert contrasts showed that the 5-year-old children were significantly different in C bias than both the 7- and 9-year-olds, p = .027. No difference there was in bias between the 7- and 9-year-olds, p = .128. All children had a positive criterion c which means they had a bias to say “not emotional” but younger children‘s criterion was significantly smaller than the two older groups, therefore they were more liberal, M (SE) = 5 years: .465(.041); 7

years: .541(.41); 9 years: .615(.040). There was no difference in the bias of the two older groups, p =.128. The main effect of emotion was significant, F (4,244) = 2.757, p = .029, η^2 = .043 as well as the main effect of intensity, F (2,122) = 114.198, p < .001, η^2 = .652. These main effects were qualified by a significant emotion x intensity interaction, F (8,488) = 10.954, p < .001, η^2 = .152. This was because children showed different bias responding to each emotion depending on its intensity. More specifically, the bias to all responses was positive, which means that children were conservative and prone to say “not emotional”. However, they were less conservative when saw a 30% of emotion intensity and this was for all emotions. The false alarm rate analysis showed a significant emotion main effect, F (4, 244) = 8.530, p < .001, η^2 = .123 which was qualified by a significant emotion x intensity interaction, F = (8,488) = 2.394, p = .015, η^2 = .038. Further analysis showed that the interaction was driven by the fearful and angry expressions: children had marginally significant higher false alarm rates when responded to 30% intensity of these emotions than 60 and 90% of intensity (all p values < .067).

ERT summary

Overall in the ERT we found differences in the accuracy of recognition of different emotions: angry expressions were recognised most accurately, while sad expressions were recognised least accurately. Furthermore, differences in accuracy were found between the 5-year-old and 9-year-old children. With regards to intensity, across all age groups and emotions, children tended to become more accurate in recognising facial expressions of emotion that were displayed at higher intensity; in fact, only the emotion faces that were at 90% intensity were recognised significantly more accurately than the emotion faces that were at 30% intensity. However, it was found that for the happy and angry facial expressions of emotion, children's emotion recognition ability was greater at 60% intensity than at 30% intensity.

Further, there was a change in C bias with increasing age. Younger children became more liberal (easier saying "emotion") than 7 and 9 year olds in the judgement of facial expressions as emotional. Furthermore, children showed different bias responding to each emotion depending on its intensity. More specifically, children were less conservative (easier saying "not emotional") when saw a 30% of emotion intensity and this was for all emotions.

The false alarm rate was higher when children responded to 30% of fearful and angry expressions.

Explicit Emotion Matching Task

The percentage correct scores were computed for each of the three intensities of each emotion and were analysed with a mixed 3 (age group: 5 year olds, 7 year olds and 9 year olds) x 3 (intensity: 30%, 60% and 90%) x 5 (emotion: happy, sad, angry, fearful, surprise) ANOVA (For means (SE) see table 4.20).

There was a significant main effect of emotion, *F* (4,292) = 51.300, $p < .001$, $\eta^2 = .413$, on the emotion matching task. Happy was significantly more easy to match than all the other emotions, p<.001. Following was the emotion of anger which was significantly different from all emotions but surprise, p<.002. Children were least accurate in matching the emotion of fear which was significantly different to all emotions but sad, p<.001. Furthermore, there was a significant main effect of intensity, *F* (1.695, 123.355) = 171.355, $p < .001$, $\eta^2 = .701$ whereby children were significantly more accurate in matching facial expressions of 90% intensity, less accurate to match the 60% and least accurate to match the 30% of emotion intensity.

The interaction between emotion and age group was significant, *F* (8, 292) = 2.157, $p = .031$, $\eta^2 = .056$. Simple effects showed that this was significant only for happy emotion, *F* (2, 73) = 4.62, p=.013, $\eta^2 = .112$. Pairwise comparisons, Bonferroni corrected, showed that matching of happy emotion significantly differed between 7- and 9-year-old children, M (SE) = 77.56 (2.9) and 89.42 (2.9), respectively, p=.016. Additionally, the main effects of emotion and of intensity were qualified by a significant interaction of emotion and intensity, *F* (8,584) = 2.952, $p < .001$, $\eta^2 = .060$. Pairwise comparisons indicated that accuracy significantly improved for all emotions with increasing levels of intensity (i.e., 60% or 90%) compared to 30% intensity (all p values < .002). The emotions of angry and fear was matched accurately at the level of 60% intensity whilst the other emotions were matched accurately at 90% of intensity

Comparison of ERT and explicit emotion matching task

As suggested by Gagnon et al. (2010), as both the ERT and the explicit emotion matching task used the same stimuli and methodology it is possible to compare the percentage correct of the two tasks. The percentage correct were analysed with separate 2 (tasks: ERT and emotion matching) x 5 (emotion) ANOVAs for each age group. Of particular interest was the task x emotion interaction. This was significant for the three age groups (5 year olds: F = (4, 92) = 4.212, p = .004, η^2 = 155; 7 year olds: F = (4, 100) = 14.249, p < .001, η^2 = .363; 9 year olds F (4,100) = 18. 258, p < .001, η^2 = .422). Pairwise comparisons, Bonferroni corrected, showed that in all three age groups the emotion of happy was matched significantly better than recognised, all p values < .045, while for sad and fear there was better recognition than matching for all three age groups, all p values <.023).

Regressions: Performance in the ERT separately for each emotion and intensity

To explore the relationship between left of right visual field advantage in the DVF task and accuracy in recognition of each of the five facial expressions at three intensities separately in the ERT hierarchical regressions analyses were conducted. Fifteen hierarchical regression analyses were conducted, with the d' scores of accuracy for recognising happy, sad, anger, fear and surprise in three intensities as the outcome variables. In the first block, age group was entered as a predictor variable. In the second block the difference between d scores of the DVF task in 30%, 60% and 90% intensities collapsed across emotions (LVF d' - RVF d'), and also its interaction with age group were entered into the second block as predictors of emotion recognition. Here, only the regressions which had significant models and significant predictors are going to be reported.

For sad 90% the first block, the regression analysis findings are presented in Table 4.26 The first block, containing age group, was not significantly better than chance at predicting sad recognition at 90%, *F* (1, 73) = 2.26, *p* =.137. The second block, with the addition of visual field d' difference (LVF-RVF) and interactive predictor, was a significant improvement on model 1 explaining 7.5 % (Adjusted R^2) of the variability in 90% sad recognition, *F* (3, 71) = 2.99, *p* = .037.

The significant predictors in the model for sad recognition included the visual field d' scores difference and its interaction with age group showing a negative relationship whereby the d' difference accuracy favouring the RVF (i.e. the smaller the LVFd' - RVFd') was associated with greater accuracy in recognising sadness at 90% of intensity. To explore the interaction further, we split the three age groups and ran the regression again. The d' scores visual field difference was only a significant predictor for the 5 year olds, who were more accurate in recognising sadness at 90% of intensity when they had a RVF (LH) advantage in the DVF task (Table 4.27).

Sad 90%

Model	Predictors	Beta	t	p
1	age	.173	1.504	.137
2	age	.154	1.360	.178
	Visual field accuracy difference (LVF-RVF)	-.695	-2.514	**.014**
	Visual field accuracy difference (LVF-RVF) X age group	.578	2.091	**.040**

Table 4. 26. Predictors of the d' accuracy for Sad 90% (significant predictors in bold).

Sad 90%:

Age	Beta	t	p
5 years	-.411	-2.116	**.046**
7 years	-.244	-1.206	.240
9 years	.134	.660	.515

Table 4. 27. Predictors of d' difference in accuracy (LVF – RVF) for Sad 90% by age group.

For fear 30%, the regression analysis findings are presented in Table 4.28. The first block, containing age group, was not significantly better than chance at predicting fear recognition at 30%, F (1, 72) =. 50, p = .482. The second block, with the addition of visual field difference (LVF-RVF) and interactive predictor, was a significant improvement on model 1 explaining 10% (Adjusted R^2) of the variability in 30% fear recognition, F (3, 70) = 3.70, p = .016.

The significant predictors in the model of fear recognition included the visual field d' scores difference and its interaction with age group showing a negative relationship whereby the greater the RVF advantage was associated with greater accuracy in recognising fear at 30% of intensity level (Table 4.28).

Fear 30%

Model		Beta	t	p
1	age	.083	.707	.482
2	age	.085	.737	.463
	Visual field accuracy difference (LVF-RVF)	-.618	-2.938	**.004**
	Visual field accuracy difference (LVF-RVF) X age group	.674	3.22	**.002**

Table 4. 28. Predictors of d' accuracy of Fear 30% (significant predictors in bold).

To further explore the interaction of the visual field difference with age group we split the three age groups and ran the regression again. The visual field d' scores difference was a marginally significant predictor for the younger children, showing a negative relationship. The more accurate younger children were to recognise fear 30% in their RVF, the more accurate were they in recognising fear 30% in the ERT. The visual field d' scores difference was significant predictor for the older, 10-year-old children, showing a positive relationship. Interestingly, greater LVF advantage (RH) was associated with greater accuracy in recognising fear at the 30% (Table 4.29).

Fear 30%

Age	Beta	t	p
6 years	-.391	-1.995	.059
8 years	-.001	-.005	.996
10 years	.422	2.282	**.032**

Table 4. 29. Predicting accuracy of fear 30% separately for each age group.

4.2.3 Discussion

Study 4 aimed to complement the finding of the longitudinal findings of study 3 (this chapter) and further explore emotion processing skills in middle childhood. Emotional faces expressing emotions in three different intensities, 30%, 60% and 90, were used in an emotion recognition task and an emotion matching task. Furthermore, the study aimed to explore whether children's recognition of emotion at differing intensities may be affected by their tendency to process emotion is the right or left hemisphere. The DVF task was used as a measure of laterality. Overall, the study demonstrates that the accuracy for recognition of emotions is emotion specific, dependent on intensity and the age of the participant. Additionally, there is evidence that laterality for processing emotions is important, only for emotions of sad at 90% and fear 30%.

Accuracy for emotion recognition improved from the lowest intensity level (30%) to the higher intensity levels. These results are overall consistent with Montirosso et al. (2010), Gao and Maurer (2009), and Herba et al.'s (2006) findings. Intensity threshold in these aforementioned studies varied slightly due to the lowest intensity used by the researchers; in Montirosso et al., children improved the most from the lowest 35% intensity and in Herba et al, children improved from 25% to the higher intensities. This is consistent with the finding in Study 4, where improvement was seen between 30% and the higher intensities. Poorer accuracy at low intensity may be due to the poor quality of emotion representation at such low intensities in the emotion recognition tasks (Gagnon et al., 2010). In the matching task poorer accuracy might be due to the fact that the features of the facial expression at lower intensities might overlap between emotions therefore cannot be encoded effectively. The results of the current study 4 show that intensity effects were not uniform across the expressions and tasks. For example, whilst study 3 showed that all emotions at 100% intensity were equally well discriminated, in the emotion recognition task of study 4 this was not the case. In particular at the lowest intensity there was greater accuracy for fear and sad compared with anger and happy. Happy and angry emotions accuracy improved between the lower intensity 30% and the subsequent, 60% intensity whereas the sad and fear accuracy improved significantly between 30% of intensity and 90%. This findings are in line with Herba et al. (2008) and Montirosso et al. (2010) who reported that fear was recognized better than other emotions at lower intensities (from 35%). This is expected from an evolutionary perspective, as from all negative emotions fear signals danger therefore may be important to recognise at lower intensities (Herba et al., 2006). This evolutionary theory has been supported by research which investigates amygdala activation, where it has been that the brain detects fear very fast through subcortical structures such as amygdala (e.g., Adolphs, 2001; Whalen et al., 1998; as discussed in Chapter 2). However, it is difficult to explain why anger, which might signal interpersonal threat (Gao, et al, 2009), is accurately recognised from 60%

of intensity and sadness, which might signal withdrawal and unavailability (Montirosso, et al., 2010), would remain less accurate in all

In addition to exploring emotion recognition, the emotion matching task showed that happy and angry facial expressions across various intensities was significantly more accurate to match than all the other emotions. Children were least accurate in matching the emotions of fear and sad in all intensities. Matching 30% of anger developed significantly from 5 to 7 years of age, but the development of 30% intensity of happy, was slow, as children became significantly more accurate at the age of 9 years. Also accuracy significantly improved matching all emotions at higher levels of intensity (i.e., 60% or 90%) compared to 30% intensity. Only accuracy matching anger fear and surprise did not improve significantly when compared 60% to 90% intensity.

Overall in both tasks, therefore, accuracy improved with age (except surprise) for happy, angry, fearful and sad expression but in different ways. Accuracy for recognition of happiness and anger was greater but children’s accuracy at lower intensities improved at the age of 9 years. Fear and sad were the least accurate expressions to match and accuracy was significantly improved in the older children group. These findings suggest an overall (for all intensities) slower development in accuracy for fear and sad and low intensity (30%) of happiness and anger, as opposed to faster development of higher intensities of happiness and anger. These findings are not entirely consistent with previous research. For example Montirosso et al. (2010) and Herba et al., (2008) found more difficult the decoding of anger and sadness. Gao and Maurer, (2009) and Montirosso et al., reported happiness and sadness as more easy to decode, irrespective of the intensity. These differences in the findings might be due to methodology differences between the studies but converge to what earlier research suggested: the ability to accurately recognise facial expression does not emerge as a unified skill; rather it develops gradually with age and varies with emotion (Herba & Phillips, 2004).

The differences between the findings of the two tasks in this study and integrated with the findings of Study 3 (Herba et al., 2006; Montirosso et al, 2010) might be attributable to the different underlying processes recruited by different tasks. For example the emotion recognition task requires that participants to match the face with an internal representation of the target emotion. The performance depends on the quality of these representations (De Sonnevville et al., 2002; Gagnon et al., 2010). Emotion matching is a visual discrimination of facial expressions and requires participants to compare faces employing a configural or featural processing depending of the similarity of the signal to the target (De Sonnevville et al., 2002).

As far as the emotions' intensity is concerned we found an increasing accuracy with increasing age at the lower intensity of 30%, which was only related to the emotions of happy and sad. The improvement for happy of 30% was observed only in older participants, (9 year olds). The improvement for sad was observed in the 7 year olds group. As the emotion recognition and emotion matching tasks touch upon different underlying processes, the improvement of performance with age and intensity is perhaps due to finer conceptual knowledge of emotions (finer representations of emotions) and a developing perceptual ability to discriminate subtle facial changes which develop together (Gagnon et al., 2010). In order to untangle this, we compared the percentage correct collapsed across intensities for each emotion and each age group of the two tasks in order to infer whether the role of conceptual knowledge of emotions or perceptual abilities develop. If children showed greater difficulty in matching the facial expressions one could conclude that perceptual limitations play an important role in the development observed in the recognition task .Conversely, if matching scores were significantly greater than recognition ones, this would suggest the limited role of the perceptual ability and perhaps we could tentatively conclude that, instead, that the performance comes from shortcomings in the conceptual development of emotional categories. This was suggested by Gagnon et al., (2010), however, we cannot compare our results because they looked at recognition and matching of disgust and fear of ages between 5 and 10 years old. We found significant differences between recognition and matching scores in all three groups. More specifically, the matching scores for happy facial expressions of emotion were significantly higher than the emotion recognition scores for all the three age groups. All children, therefore, are able to discriminate facial features of happy facial expressions of emotion but the conceptualization of happiness suffers. This imperfect conceptualization of happiness it must be relevant only to the 30% of intensity because happiness of 60% and 90% was recognised with great accuracy. In other words the 30% of happiness does not match the prototype representation of happiness for the three age groups, and this category of “happy” is refined significantly at the age of 9 years in this study. In contrast to happiness, sad and fearful expressions had significantly higher recognition scores than matching scores. This result, points to the perceptual limitation of all three age groups, whilst their conceptual knowledge of the three emotions as distinct categories seems to improve with age and within the three age groups.

Is the conceptual and perceptual development observed linked with the degree of hemispheric bias for different emotions? This was one of the main aims of this study, to explore how children’s performance in recognition of emotion at differing intensities may be affected by their tendency to process emotion is the right or left hemisphere using the DVF paradigm as an alternative measure of laterality.

We found some evidence, that the greater accuracy when an emotional face was presented in the LVF (RH), significantly predicted greater accuracy of fear facial expressions recognition at 30% of intensity only in the 10-year-old children. This is an interesting finding because shows a development of laterality bias to the right hemisphere between 5 and 9 years of age. Workman et al., found the same pattern in the development of right hemisphere laterality for fear processing.

Interestingly, while the previous finding was for 30%, for the processing of sad facial expressions of emotion there was a pattern emerge at 90%, whereby the 5 year olds who were more accurate when facial expressions of emotion were presented in the RVF were more accurate on the emotion recognition task. While this goes against the finding of a LVF preference increasing accuracy on emotion recognition tasks, there is some support for this finding from Workman's et al., (2006) who found that 5-6 year olds had no laterality bias. Additionally, earlier findings (study 3) reported in this thesis also showed that 6 year olds had not laterality bias for sad processing.

We found, therefore, using a DVF task some indication of a shift of laterality bias to the RH for emotion processing which predicts greater accuracy in emotion recognition tasks, which supports previous findings (e.g., Watling & Bourne, 2013, under review; Workman et al., 2006). However, we failed to find developmental trends of laterality and relationships between the laterality task and emotion recognition tasks for all the emotions in our study, comparable to the CFT. Laterality in children has predominantly been investigated by means of the chimeric faces task, where emotional chimeras are presented centrally one above the other. The DVF task for emotion processing has been only used with adults as it is a difficult one requiring participants to judge faces which they see in their visual periphery. It could be that the task itself was too demanding for our three age groups of children even though they all performed above chance and that, the chimeric faces task is more child friendly and a more reliable measure of laterality in children. Another possible explanation is relevant to the tasks themselves. It might be that the DVF task taps upon implicit processing of the emotional information. It was discussed in chapter 2 that the literature is consistent with the distinction of the conscious and unconscious mechanisms of emotional processing. For instance Williams et al., (2009) used both explicit and implicit emotion recognition tasks using accuracy and reaction times measures. Accuracy and reaction time had the opposite pattern for explicit and implicit recognition of emotion. In the explicit condition the responses to happy facial expressions of emotion were more accurate and the responses for fear facial expressions of emotion were the slowest. In the implicit condition exactly the opposite was observed, where the responses to facial expressions of fear were more accurate and the responses to happy facial expressions of emotion were the slowest. This could explain why we only found visual field effects only for fear 30% and sad 90% of intensity. It is interesting that these two emotions appeared to have visual field bias at such intensities: Fear is given priority in the implicit emotion processing (Adolphs, 2002; Eimer & Holmes, 2002; Whalen et al., 1998) and Gao et al., (2009) reported that children tend to misidentify sad as fear.

To conclude, results indicated that both discrete emotion categories and emotion intensities are differentially processed across the three age groups studied here. There is evidence of visual field advantages in processing of different intensities of different emotions and that a shift to left visual field advantage predicts the accuracy in recognition of the emotion of fear.

4.3 Conclusion

The main focus of this chapter was in exploring the development of facial emotions processing skills and whether this development is related to the development of hemispheric asymmetry. More specifically two studies presented longitudinal and cross-sectional evidence that there is a relationship between the strength of lateralisation for emotion processing and emotion recognition performance, albeit this relationship did not exist for all emotions.

Through this chapter it was shown, first, that children do develop in their emotion recognition from faces but the development varies with the emotion, the intensity and task at hand. In other words, both, discrete emotion categories and emotion intensities were differentially processed across middle childhood. Second, hemispheric asymmetry develops but with different rates for each emotions. Importantly, there was clear evidence that association between the development of laterality for facial emotion processing and children's ability to accurately match facial expressions which was predicted by developmental changes in strength of lateralisation. Specifically, children who developed stronger right hemisphere lateralisation for emotion processing performed better in the task. Findings with the DVF task also supported the aforementioned finding with the link between visual field processing and accuracy on the emotion recognition task. The shift of hemispheric bias to the right was also found to predict greater ability to recognize fear at 30% of intensity. Taken together, these findings support earlier ideas presented throughout this thesis that children's accuracy for recognising facial expressions of emotion increases throughout the childhood years, and specifically that links between laterality for emotion processing and emotion recognition performance is dependent on the emotion under investigation and the task used, with stronger links found where task performance is beginning to develop (more difficult). Furthermore, the improved accuracy at lower intensities of facial emotion expression showed the refinement of facial emotion recognition skill with age.

These results reflect the varying developmental course of the processes (conceptual knowledge and perceptual discrimination) recruited in the different tasks and might offer some insight into why there are different accuracy levels across tasks even for emotions that are well known to develop at adult level such as happy. It was discussed earlier in this thesis that greater accuracy in emotion identification and discrimination means an improved quality, and refining of the prototype of each specific category or emotion. Gagnon et al. (2010) and Widen and Russell (2003) put forth the incremental conceptual differentiation hypothesis, whereby emotion categories gradually emerge by refining previously acquired concepts of broader categories of emotions (see chapter 1 and chapter 2.). The two studies support this hypothesis. It appears that the conceptual knowledge of emotions that are recognised well and early as distinct categories is being refined with age. This is shown by the development we saw of 30% of happy. On the other hand there are emotions, especially those that are similar in facial configuration, such as sad and fear, which we found that were more difficult to match and developed with age. Matching depends on the quality of visual discrimination, emotion decoding skills from faces, and analytical face processing skills (De Sonneville et al., 2002). The ongoing maturation and refinement of the visual system which might be ongoing even in later childhood (Gagnon et al. 2010) may offer insight into the findings presented in this chapter.

The visual discrimination ability (emotion matching) was greater for girls only in the 100% intensity matching task. Female ‘superiority’ in processing facial expressions of emotion have been explained by anatomical differences, different rates of maturation of neurological structures responsible for emotion processing, and also by differences in the social experience (Bourne, 2005; Lin, 2009). Sex differences in emotion processing in children have not been found in a consistent way (Gross & Balliff, 1991; McClure, 2000). However, the sex effects found in the first study of this chapter are very interesting if seen in the light of laterality development which is the main focus of this chapter.

The main focus of this thesis is the development of laterality and how it is associated with the developing facial emotion recognition skills. The three main points raised from the two studies are related to established laterality, laterality development, and the relationship of laterality with facial emotion recognition skills.

Firstly, there is support to the reports so far in the literature: when emotion processing skills reach proficiency then the degree of established right hemisphere advantage becomes significant (Watling and Bourne, 2013, under review). This finding if further advanced by the key finding of the chapter, that development of laterality is important for the development of facial recognition skills. Secondly, a novel finding of these two studies is that laterality development predicts children's performance in the emotion matching task. This was found mainly in the first study, and has been partially supported by the second study which used different measure of laterality. This finding is very important because it sheds light to the direction of a relationship, which has been reported to exist between right hemispheric asymmetry and facial emotion recognition skills (Watling & Bourne, 2007, 2012; Workman et al., 2006). Interestingly, laterality development predicts performance only in a task which was more difficult for the children (emotion matching) and not in a task where children performed at ceiling (emotion discrimination and emotion recognition at high intensities). It could be argued, therefore, that laterality development in emotion processing becomes important when children are becoming proficient in a task or in recognition of a specific emotion (e.g., 30% of intensity for fear). Thirdly, the development of laterality for emotion processing was only found for boys. Interesting, while boys' performance was less accurate than girls' performance, boys performance was better when strength of laterality to the right hemisphere was greater. It is possible that this relationship with laterality and performance for boys may compensate for lower emotion recognition ability. However, this conclusion must be taken with caution as when looking at happy, sad, and angry emotion matching separately, this aforementioned relationship only was significant for the facial expression of

In summary, the findings in the two studies in this chapter further advance our current understanding of facial emotion recognition development and explain some inconsistencies reported in the literature. They bear, therefore, important implications of how we understand the development of facial emotion processing skills.

Chapter 5: General Discussion

5.1 Main findings

The aim of this thesis was to investigate the development of hemispheric asymmetry and its relationship with different facial emotion processing skills. This question was tackled using diverse approaches that included electrophysiological EEG (Chapter 3) measures and behavioural measures (Chapter 4). Four general conclusions can be drawn from the empirical investigations presented within this thesis.

First, there is indication that the CFT is a test of laterality. Electrophysiological activity, as shown in study 1 (chapter 3), is consistent with the visual field bias of the two laterality groups and the contralateral effect of the two visual fields. The RH laterality group (those who identified the chimeric face with the emotion in their LVF as more emotional more often than when the emotion was in their RVF) had greater activity over the RH whilst the LH laterality group (those who identified the chimeric face with the emotion in their RVF as more emotional more often than when the emotion was in their LVF) had greater activity over the LH. In study 2 (chapter 3) the effect was attenuated by the implicit CFT which was used.

It was evident in children early in the processing for all chimeric faces irrespective or valence (children had greater activity over the RH). The effect of visual field was an effect observed only on the RH which was affected by the LVF presentation of the emotion.

Second, the development of standard facial emotion sensitive ERPs, seen in study 1 in adults, was reflected in reduction of amplitudes with increasing age in study 2. Furthermore, at the late time window (180-400ms after stimulus onset) the laterality patterns differed between children in middle childhood, children in late childhood and adults. More specifically, middle childhood group had greater activation in the LH when presented with sad facial expressions of emotion, whilst children in late childhood and adults had greater activation over the RH.

Third, study 3 (chapter 4) and study 4 (chapter 4) demonstrated that children's emotion recognition skills develop and this development varies depending on the emotion, the intensity, and task measurement. In other words, both discrete emotion categories and lower emotion intensities are recognised better with age, girls performed better than boys in the emotion matching task.

Fourth, and most importantly, study 3 and study 4 provided evidence that there is an association between the development of laterality for facial emotion processing and children’s ability to accurately recognize and match facial expressions of emotion. Children’s strength of lateralisation for emotion processing was a significant predictor of emotion discrimination ability one year later. Additionally, children who developed stronger right hemisphere lateralisation for emotion processing over the period of a year performed better in the emotion matching task. This relationship between right hemisphere lateralisation development for emotion processing and emotion matching of sad facial expressions of emotion was significant only for boys. The relationship between right hemisphere lateralisation development and emotion matching of angry facial expressions was significant only for the 6 year olds (Study 3).The shift of hemispheric bias to the right was also found to predict greater ability to recognize fear at 30% of intensity and sad at 90% of intensity (Study 4). This relationship between the development of laterality for emotion processing is specific to emotion recognition performance, and not to identity recognition tasks (even if emotion is varied).

The following discussion will further explore these four general findings with reference to the implications for our understanding of how children understand emotions. Further I will explore the practical implications and the limitations of the present research alongside suggestions for future research.

5.2 General Discussion

Previous research into the development of emotion processing has mainly used behavioural measures to investigate the development of laterality, with the main measure used being the chimeric faces test (CFT). The CFT capitalizes on the crossed nature of the visual system which projects information from one half of the visual field directly to the opposing hemisphere. Emotional chimeras are faces made to show an emotional expression on one half of the face and a neutral expression, from the same poser, on the other half. A chimera is presented centrally with its mirror image, one above the other and the participant is asked to decide which of the two chimeras looks more emotional. Study 1 is the first ERP study to date exploring the cortical neural correlates of this behavioural task.

Study 1 (chapter 3) indicated that the CFT is a test of laterality. The electrophysiological activity observed when the two laterality groups (those more strongly RH lateralised and those less strongly RH lateralised for facial emotion processing) was consistent with the visual field bias of the two laterality groups and the contralateral effect of the two visual fields. Specifically, the more strongly RH laterality group (those that chose the chimera in their LVF as more emotional than when in their RVF) had greater activity over the RH, whilst the less strongly RH laterality group (those that chose the chimera in their RVF as more emotional than when in their LVF) had greater activity over the LH. More generally, regardless of an individual's strength of laterality (using behavioural measure), when shown an image of a chimeric face with the emotion in the LVF there were greater amplitudes over the RH hemisphere, and when shown an image of a chimeric face with the emotion in the RVF there were greater amplitudes over the LH. Importantly in the middle time window (VPP) there was an interesting pattern of asymmetry depending on the visual field of emotion presentation, only for sad chimeras. When the emotion of sad was presented in the LVF a large asymmetry was observed between the recordings across the two hemispheres. When sad emotion was presented on the LVF there was greater amplitude over the RH than the LH was observed; whereas when the same emotional information is presented in the RVF there was no significant difference between the amplitudes in the two hemispheres. This effect implies a genuine underlying perceptual bias which mirrors the behavioural evidence of a bias to processing emotion from the left or right visual field and provides its neurophysiological correlate. In study 2 (chapter 3) the effect of visual field on hemispheric asymmetry was attenuated by the implicit processing of the CFT stimuli (i.e., participants were asked to passively view, not explicitly judge the emotional stimuli.). The effect of visual field was observed only on the RH where activation was stronger when there was LVF presentation of the facial emotion information.

The findings indicate that the CFT is a test of laterality, but more specifically is a test of laterality when the task is explicit but not when it is implicit. In other words the hemispheric differences in chimeric faces processing are observed when attention is directed towards the emotion of the chimeric faces (i.e., participants are making a judgement about the emotiveness of the stimuli). As discussed in chapter 3, the absence of laterality effect in an implicit chimeric faces task could be because of emotional chimeras' lack of ecological validity. It is possible that when free viewing the chimeric face stimuli if attention is not directed to the emotionality of the stimuli more facial and featural information is being processed in the early stages rather than emotive information. Another possibility is that implicit emotional processing requires subcortical structures that EEG does not have access to (in particular the amygdala). This explanation is supported by the fMRI study with chimeric faces by Killgore and Yurgelun-Todd (2007) who found the contralateral effect of visual field of emotion presentation on subcortical structures.

5.2.1 Development of behavioural and neuropsychological processing of emotion

5.2.1.1 Developmental trends in Emotion Processing

Emotion Recognition skills

First, it was found that there is significant improvement in emotion recognition accuracy over the time period of one year for 6- to 10- year-olds and that this improvement varied with the emotion and the task. As I discussed in chapter 1, developmental affective research so far has used a variety of tasks; as a result, researchers report slightly different ages at which different emotions are recognised. This is because each task examines different underlying processes. For instance, emotion labelling, identification, and discrimination tasks examine emotional knowledge, whereas emotion matching tasks examine visual discrimination ability (discussed in chapter 2). This research supports previous work that different emotional processing abilities required for different tasks (shown in Study 4, chapter 4) develop at different rate, as was shown through age group differences, and for different emotions.

In the emotion discrimination task (Study 3, chapter 4), accuracy levels were generally high (above 90%), yet there was a development as it was shown by the main effect of time (increase in performance over the course of one year). Additionally, it was shown that accuracy differed depending on age group and on emotion (from the six facial expressions the least accurately discriminated was that of fear). The results are partly in line with results found in studies which used discrimination tasks (Bullock & Russell, 1985; Durand et al., 2007; Gagnon, Gosselin, Hudon-ven der Buhs, Larocque, & Milliard, 2010; Vicary, Reilly, Pasqualetti, Vizzotto, & Caltagirone, 2000). These studies report development in discriminating emotions throughout middle childhood, with fear being discriminated later than the other emotions (just before the disgust). As an emotion discrimination task requires that children compare and match configural characteristics of a facial expression with the internal representation of a specific emotion, thereby employing configural processing (De Sonneville et al., 2002), the work in this thesis shows that of the six facial expressions examined (happy, sad, anger, fear, surprise, and neutral) the one most poorly defined representation is that of fear. Our finding, therefore, could be explained by the incremental conceptual differentiation hypothesis, whereby the concept of fear gradually emerges from previously acquired concepts of happiness, anger, and sadness (Gagnon et al., 2010; Widen & Russell, 2003, 2008).

In the emotion matching task there was a slightly different pattern of development. The results in chapter 4 suggest that the visual discrimination of emotions of happy, sad, and angry facial expressions improves with age. Emotion matching involves comparing and matching facial features employing an analytic encoding of faces (Karayanidis et al., 2009) and it is thought to impose high demands in children (De Sonneville et al., 2002).

If the emotion discrimination task requires configural processing and the matching task employs rather analytical processing then what our findings indicate is different developmental trajectories for processing configural and featural information. As discussed in chapter 1, there is a debate as to whether the development of the ability to recognize emotions from faces is underlied by the development of the ability to process configural information or the development of analytical processing skills (Durand et al., 2007; Kestenbaum, 1992). The findings show the latter and are comparable to those of Durand et al. (2000) who found that children at the age of 5 process facial emotion in a configural/holistic way; however, they contradict other findings (Kestenbaum, 1992) which indicated that there is a continuum of processing from reliance on individual features to a more holistic processing and that the processing of different emotions varies along this continuum. Further research is needed to clarify the direction of the development on this continuum.

The findings in this thesis suggest development of the visual system between 6 years and 8 years and between 8 years and 10 years of age. Gagnon et al. (2010) suggest that the specific development of the visual system is ongoing beyond the age groups explored in this thesis (i.e., into late childhood). The pattern of development found in our study is similar to that reported by De Sonnevillle et al., (2002).

In addition to the two emotion tasks above, the identity matching task showed that emotive information in the images affected children's performance. Identity matching is an implicit emotion processing task and it involves ignoring the emotive information and focusing on identity matching. The work in study 3 (chapter 4) showed that with age there was a decrease in the interference of emotion information on identity matching; more specifically, sad and surprised facial expressions of emotion were the emotive images that children had the most difficulty inhibiting when attempting to match identity at time 1 of testing, but one year later (at time 2 of testing) these two emotions were less likely to interfere with identity matching. It has been suggested that such a task provides an index of subcortical neural correlates of emotion processing and performance depends on the maturation of subcortical emotion specific structures such as amygdala (De Sonneville et al., 2002; Herba et al., 2006; Lobaugh, Gibson, & Taylor, 2006). Our findings reflect this on-going maturation between 5-10 years of age, which is consistent with Herba et al.'s findings in a similar task.

In addition to emotion recognition at 100% (study 3), children's sensitivity to nuances in facial emotion recognition was explored for facial expressions of emotion at lower intensities (30%, 60% and 90%; study 4). Overall, in study 4 (chapter 4) it was found that accuracy improved with age for happy, angry, fearful and sad expressions (exception was surprise), but in different ways. Fear and sadness were the least accurate expressions to match and accuracy was also improved at the age of 9. Overall, children are fairly proficient recognising emotions at 60% and 90%, however, there was variability in emotion recognition of images at 30%. Accuracy for the recognition of happiness and anger improved from 30% intensities to 60% of intensity at the age of 9 years. These findings suggest an overall (for all intensities) slower development in the accuracy for fear and sad facial expressions of emotion and accuracy at low intensity (30%) of happiness and anger facial expressions of emotion, as opposed to more rapid development of higher intensities of happiness and anger. These findings show that the development of facial emotion recognition skills does not emerge as a unified skill; rather, it develops gradually with age and varies with emotion and its intensity (Herba & Phillips, 2004).

Whilst these results depict the how the developmental course may vary for different emotion recognition tasks which may depend on different emotion processing skills (i.e., conceptual knowledge and perceptual discrimination), at a neuronal level (in study 2, chapter 3) the development was reflected as decreasing ERP amplitudes with increasing age and this was more specific to the facial expression of sad emotion. The decrease in activation with age was explained by Batty and Taylor (2002, 2006) as an “effect of maturation”, and indicates a progressive decrease in cortical activation due to continuing maturation and increased myelination of the neural pathways. Additionally, the developmental trend for the recognition of the emotions of sad and happy is also reflected in ERP deflections: the sad facial expression images were processed differently than happy facial expression images and neutral facial expression images, with the key in the findings between children in middle childhood (5-8 years) and adults (no difference between children in late childhood and adults). There is correspondence between the implicit behavioural task above (i.e., the identity matching task) and the implicit task in the ERP study (study 2, chapter 3) as far as the development of sad expression is concerned. Further research is needed to explore whether behavioural findings of other emotions' recognition are mapped onto the electrical activity of the brain.

5.2.1.2 Laterality Development

In addition to emotion recognition age trends, this research (primarily) considered the development of hemispheric asymmetry for emotion processing. I discussed in chapters 1 and 2 that recent research has examined the role of the maturation of brain structures in emotion processing; one line of this area of investigation is the development of brain lateralisation. Studies which explored the development of laterality for processing emotions gave support to the progressive viewpoint of hemispheric asymmetry (Boles, Barth, & Merill, 2008). According to progressive viewpoint, hemispheric lateralisation develops throughout the childhood years. When exploring laterality for emotion processing using the CFT, the longitudinal study 3 (chapter 4) demonstrated that 8-year-olds and 10-year-olds are right hemisphere lateralised for the processing of all three emotions, happy, sad, and angry. The 6 year olds were right hemisphere lateralised for processing happy and angry emotions but they were only weakly right lateralised for processing the emotion of sad. We observed a continued development where children's RH laterality was strengthened over the course of a year. This research therefore, replicated previous research (e.g., Levine & Levy, 1986; Watling & Bourne, 2007, 2013, under review; Workman et al., 2006) whereby there are developmental age differences in the strength of lateralisation between the ages of 6 and 10 years. The aforementioned research has provided converging evidence that by 10 years of age children are right hemisphere dominant at a similar level of adults. Additionally, even when using a test of laterality other than the CFT, the Divided Visual Field (DVF) paradigm, the same right hemisphere bias development was observed in children between 6 to 10 year olds when the facial expression of emotion was at 30% intensity and was presented in their LVF.

Interestingly, while the behavioural tests of laterality with children (Studies 3 and 4) showed right hemisphere dominance in the lateralisation for emotion processing, the physiological data, with children (Study 2 EEG work), only showed the development of laterality for the emotion of sad. When presented with sad facial expressions of emotion, in comparison to neutral expressions, the

ERP laterality patterns of activation differed between the children in middle childhood, children in late childhood, and adults. Specifically, in the late processing epoch (P300) the children in middle childhood (5-8 years) had greater activation in the LH, indicating this is where they were distinguishing the emotion of sad, whilst children in late childhood (9-13 years) and adults had greater activation in the RH. Further research is needed to compare the laterality development reported for all of the basic emotions (Workman et al., 2006) to the cortical activity in children's brains.

It is also interesting that the RH bias was found for emotions of sad and fear in the DVF task. It might be that the DVF task taps implicit processing of the emotional information, contrary to the CFT which is explicit. Fear is given priority in implicit emotion processing (Adolphs, 2002; Eimer & Holmes, 2002; Whalen et al., 1998) and sadness is misidentified by children as fear (Gao et al., 2009). These points combined support the distinction between the conscious and unconscious mechanisms of emotional processing reported in the literature, (e.g. Critchley et al., 2000; Knyazev et al., 2009; Williams et al., 2009) which could explain our findings in the DVF task.

5.2.1.3 Relationship between laterality development and facial emotion processing skills.

Recent research has examined the relationship between the neuropsychological processing of facial expressions of emotion (strength of laterality) and the ability to recognise emotions. To date, Workman et al. (2006) and Watling and Bourne (2007) found a relationship between the strength of lateralisation and social-emotion understanding, respectively. For instance, Workman et al. (2006) found that degree of laterality was important for better performance in the emotion in the eyes and situational cartoon tests and this was found only for 5-6 year olds. More recently, Watling and Bourne (2013, under review) reported a positive relationship between the strength of lateralisation for processing happy facial emotions and children's performance on an emotion discrimination task. They found that the relationship only existed for the 6-year-olds and not for the 8- and 10-year-olds. In this thesis, Study 3 showed the same relationship between the ability to discriminate happiness from other emotions and the strength of lateralisation for processing happiness. Specifically, 6 year olds who were more strongly lateralised to the right hemisphere for processing happy emotions were more accurate in their recognition of happy emotions. Happy emotion is one of the earliest emotions to be recognised to a similar level as adult recognition and is the earliest emotion to have similar strengths of lateralisation for processing as adults do (Herba & Phillips, 2004; Workman et al., 2006). If we take into account the above points and the findings by Castro-Schilo and Kee, (2010) who reported that established emotional intelligence (EI) ability was associated with stronger right hemisphere dominance, then we can assume that when emotion processing skills reach proficiency levels then the degree of established right hemisphere asymmetry becomes significant.

Of particular importance and novel within the findings of this research is the role of the development of laterality in the development of the processing skills for emotions that are not fully developed; two such emotions are sadness and anger. In fact, study 3 (chapter 4) showed that the role of laterality development varied depending on the task and emotion. Changes in laterality were not predictive of emotion discrimination, although laterality was significantly predictive of emotion discrimination (time 1 laterality for emotion processing was a significant predictor of time 2 performance). In contrast, a change in laterality across the year was predictive of children's performance in the emotion matching task, but not the identity matching tasks. Children who developed greater right hemisphere asymmetry over the one year period for emotion processing were more accurate in their emotion matching performance at time 2 (and after controlling for performance at time 1). Furthermore, when linking increased strength of laterality for processing to increased accuracy of specific emotion performance, the development of hemispheric asymmetry for processing of sad emotions was significant only for boys, and of angry emotions was significant only for 6 year olds.

5.2.1.4 Sex Differences in laterality development

In addition to the age trends that were found, it is important to consider the facial expression processing skills and laterality development for boys and girls separately. Indeed, the finding that being a girl is predictive of more accurate emotion recognition skills in matching facial expressions is consistent with previous literature (e.g., McClure, 2000). However, of interest is the finding that for boys' developmental changes in laterality for emotion processing, over a one year period, is predictive of emotion matching skills. Work by Bourne (2005) has suggested that men are more strongly lateralised than women; however, in our sample (study 3, chapter 4) there was no significant sex difference in strength of lateralisation, including no interactions with age group or of time of testing. This does not support the idea that the boys may be delayed in developing stronger RH lateralisation for emotion processing. Taken together, this research indicates possibly that boys who develop a higher strength of lateralisation may compensate for lower emotion recognition ability. However, this conclusion must be taken with caution as when looking at happy, sad, and angry emotion matching separately, this aforementioned relationship only was significant for the facial expression of sad.

5.2.2 Practical Implications

5.2.2.1 Cortical brain correlates of behavior

Before exploring how cortical brain development may influence behaviour, it is important to highlight that this thesis provided key electrophysiological evidence that the chimeric faces test (CFT) is a test of laterality. It was discussed in chapter 2 that the CFT is a widely used behavioural measure of emotion lateralisation (Bourne, 2010; Levy et al., 1983). Kucharska-Pietura and David (2003) validated the CFT as a test of laterality for emotion processing with patients with unilateral brain lesions. In their study, they compared the judgements of chimeric faces with a group of individuals who had either left or right hemisphere brain damage, and a healthy control group. They found a left visual field bias (RH advantage) in both the controls and the patients with unilateral left hemisphere lesions when judging chimeric faces; however, patients with unilateral right hemisphere lesions showed a significantly reduced left visual field bias. Similarly, Bava et al. (2005) reported the same bias in children with unilateral congenital brain damage. Neural correlates of this behavioural test had not been explored so far. This is the first study to show that behavioural evidence of having a bias to processing emotion on the left or right visual field has a neurophysiological correlate and therefore can add to the understanding of how changes in emotion processing for facial emotions throughout development may interact with (or influence) emotion recognition performance.

As discussed in chapter 1 research investigating children's developing facial emotion recognition skills typically explains this development through two different influences: social factors and maturation of the brain. This thesis has focused on the latter, maturational changes in the brain. Greenough et al. (1987) considered the possible interaction between brain development and the environment and proposed two different processes which differ depending on the importance for typical development (experience expectant) and the times at which development or neural changes can occur (experience dependent).

An experience expectant process is a neural preparation of the organism to incorporate specific environmental information. For instance, in many sensory systems synaptic connections between neurons are overproduced, but a subsequent experiential input determines which of them survive. Therefore, if an individual does not receive the necessary input from the environment during a specific period of development (i.e., the critical or sensitive period) the brain develops in an atypical way and, as a result, impairments in processing that type of information occur. For example, infants with early visual deprivation, resulting from bilateral congenital cataracts, have been found to have impaired face-processing abilities later in life after the cataracts have been removed (Geldart, Mondloch, Maurer, De Schonen, & Brent, 2002; Greenough et al, 1987). In contrast to the experience expectant, the experience dependent processes appear to involve active formation of new synaptic connections in response to the environmental information to be remembered, which is unique to the individual, for example, recognising a happy face in their environment. In other words experience dependent processes promote adjustment to specific environments in life and create "sequential dependencies" (Marshall & Kenney, 2009) where the development of one skill is dependent on having previously developed other skills, which may then be refined. For example, in order to process facial emotion the individual must first have the ability to perceive the visual input of facial stimuli (Watling et al., 2012). This view emphasises brain plasticity and individual differences in development (Marshall & Kenney, 2009). It is clear from this account that brain and environment interactions are of a great deal of importance for understanding developmental processes more generally. Therefore, differences in social experiences may play a part in influencing the development of facial emotion recognition, such as exposure to emotional displays (Gordon, 1989) and levels of expressivity at home (e.g., Camras et al., 1990). The other explanation is that neurological development influences facial emotion recognition.

This thesis provided evidence on the relationship between brain processes and a certain ability, recognition of emotions from faces. More specifically, one of the key aims of this thesis is to develop an enhanced understanding for how at the same time children are developing emotion recognition skills the emotion processing in the brain is also developing (changing). To assess this, evidence was provided with both electrophysiological correlates of behavioural bias and behavioural evidence and how this links with performance between middle and late childhood (approximately 6- to 12-years). This study used both cross-sectional and, crucially, longitudinal data to provide insight into how emotion recognition skills may develop. It appears that that the two aspects of the experience expectant/dependent debate are continuously interacting aspects of development: different patterns of lateralisation impact on emotional behaviour which in turn influences the social experiences.

The research in this thesis supports the view that with age there is an increasing refinement in the facial emotion recognition ability (accuracy) and that the development of the ability to recognize emotions from facial expressions is not the same for all emotions. It also showed that this variability in the emotion recognition skills in children can be predicted by established laterality and developmental changes in right hemispheric asymmetry. The mapping of the emotion recognition skills with brain processes is very important for promoting our understanding of emotion processing in children.

I discussed in chapter 1 that understanding the neural markers of this development in healthy child populations is crucial. It will contribute to an integrated model for emotional development that may better explain our current understanding and explain the roles of the hemispheres in the processing of emotional stimuli (Killgore & Yurgelun-Todd, 2007; Mneimne et al., 2010). Further, exploring how lateralisation for emotion processing and its development may influence children's emotion recognition skills throughout childhood allow one to develop an enhanced understanding of the normative development of emotional recognition. Not only can we inform knowledge of deviance or psychopathology, as well as integrate this better understanding into the design and provision of prevention and intervention, but we can also enhance our understanding of the risk factors that might influence normative development and lead to an emerging disorder (Cicchetti & Rogosch, 2002).

Age differences in facial emotion recognition and hemispheric asymmetry in emotion processing have been supported by maturational changes in brain structures such as the corpus callosum. It was discussed in chapter 1 that the corpus callosum plays an important role in the development of hemispheric asymmetry. The corpus callosum is a large neural band of fibres and consists of many pathways or channels each responsible for transferring a distinct type of information making the interhemispheric communication and integration of information from the two hemispheres possible (Banich 1998). Several investigations on the structural and functional properties of the CC suggested that CC increases in size over childhood are due to myelination of its axons. With maturation, CC maintains an equilibration in its function and contributes to the development of hemispheric lateralisation of function supporting the behavioural findings reviewed above for the development of laterality. With an immature CC on the other hand, transfer is slow, resulting in unbalanced lateralised processes.

The question arises as to whether CC maturation with development bears any relevance to the developmental emergence and maturation of perceptual processes generally and whether the age at which lateralisation of a distinct process occurs modulates the relationship between lateralisation and performance across lifespan. This was addressed by Boles et al. (2008) who indicated that individual differences in maturation of CC or developmental restrictions at different ages of childhood can account for these relationships.

The Boles et al. (2008) model proposed that the timing of when the brain becomes lateralised leads to differential relationships being found between hemispheric processing and related task performance. For instance, they showed that language processing, which is lateralised in the brain very early in childhood, has a positive relationship with childhood performance in linguistic tasks but with age this relationship declines. However, according to this model, as the brain becomes lateralised for emotion processing in early to middle childhood, it is expected that links with emotion task performance will be negative in childhood but with age (by adulthood) this relationship will be positive. Interestingly, more recent evidence and the research in this thesis refute this model (e.g., Watling & Bourne, 2013, under review; Workman et al., 2006). Throughout this thesis, and in particular in the longitudinal work there was clear evidence that there was a relationship between laterality and performance in childhood, as well as the fact that increasing hemispheric lateralisation in childhood was predictive of increases in performance. Perhaps the model of Barth and Boles is relevant to associations between laterality and performance only for adults.

5.3 Limitations of this research and Future Directions

The work in this thesis has been important in providing the electrophysiological correlates of the behavioural CFT and in identifying the role of neural processes in the facial expression recognition skills in developing children. The studies in this thesis have extended our knowledge of the mapping of processes that have been investigated behaviourally onto the brain. However, there are some limitations of the work within this thesis in developing firm conclusions about the relationship between laterality for emotion processing and emotion recognition skills, which should be addressed in future research.

As discussed in chapter 2, the EEG technique has excellent temporal resolution and it provides an online measure of processing between a stimulus and a response making it possible to determine which stage of processing is affected by a specific experimental manipulation (Luck, 2005). However its disadvantage is that it has poor spatial resolution (it does not provide spatial information of the processing) so it is not possible to determine where in the brain the processing is occurring. In research which explores laterality, this is a clear limitation and the conclusions drawn are only tentative which require further research. For instance in our research the difference between the ERPs indicate a difference in the processing but whether the processing is on the left or the right hemisphere is not fully informative. As discussed in chapter 2 (section 2.3.2), with the volume conduction in the brain the activity spreads out laterally and blurs the cortical distribution of voltages; in other words, the activity recorded could come from anywhere in the brain. One way around this would be to use source analysis to locate the dipoles that generate the activity observed.

In addition to simply limitations of EEG work, there are three methodological considerations that could enhance future research. First, it is possible that the amplitude of activation was due to additive effects of planning the response (pressing the response key). In study 1 participants were asked to respond with only one hand (i.e., their right hand) using their index and middle finger for responses. As hemispheric asymmetry was the key aim of this study it would be interesting to see whether there would be hand response potentials differences. Second, the EEG work in this thesis used a 10-20 system, limiting the number of recording sites. As was discussed in Chapter 2, literature justifies recording from the frontocentral sites and that for every posterior ERP there is an anterior equivalent of opposite polarity. However, emotion is processed by several cortical and subcortical structures which comprise the emotion circuitry. It would be interesting to see activity patterns at additional recording sites. Third, whilst we wanted to compare explicit versus implicit electrophysiological activity patterns, the finding that explicit measures were more likely to show links between laterality for emotion processing and performance on emotion recognition tasks, it would be interesting to see ERP responses in an explicit emotion processing task at different ages in childhood (as well as for stimuli at lower intensities).

One particular limitation, and also an opportunity for extension of the current work, is that there were only two (in studies 1 and 2, chapter 3) or three (in studies 3 and 4, chapter 4) emotions used in the tasks when looking at hemispheric emotion processing. Through the work of Workmen et al. (2006) and the work in this thesis that demonstrates different trends in the development of laterality for emotion processing, it would be important to include all of the six basic emotions. Particularly, many studies tend to contrast the hemispheric processing of one positive emotion (typically happy) and one negative emotion (typically fear). However, there is little research investigating the neural processing of all emotions. Extending work to include all 6 basic emotions (and neutral) would enable researchers to compare findings and extend the understanding of how emotion processing in the brain works.

One point that could be made is that the emotion recognition tasks required a control task that did not involve faces; in the work presented in this thesis, the identity matching was a control task but this was about faces. However, this does not limit our research as the question of whether the development of emotion recognition ability is part of a more general cognitive development or even part of the ability to recognise a face was addressed by Johnston et al. (2011). Johnston and colleagues investigated the development of facial emotion recognition and facial identity skills using emotion and identity matching tasks that were equal in discrimination difficulty in adults, and they also used a pattern matching task to control for general discrimination improvements. They tested children from 5 to 15 years old and an adult group so that they could see the endpoint of the development. They found first that in 8- to 15-year-olds the development of facial expression of emotion discrimination lagged behind the identity discrimination and non-face tasks, but also that the scores in the non-face matching task predicted the performance only of the face identity task in all ages. What the study showed is that general and specific identity discrimination abilities develop earlier than the facial emotion discrimination. Importantly, it also showed that emotion recognition development is independent and distinct from a general cognitive development.

In summary, further research should explore the hemispheric laterality of all six basic emotions (happy, sad, anger, fear, surprise, and disgust) if we are to have a more complete picture of laterality development and its relationship with emotion processing development. Whilst this research provided invaluable evidence of the relationship between the development of laterality with different facial expression processing skills and performance on emotion recognition tasks, the analysis was focussed on the predictive relationship of the development of laterality and did not examine causal direction of the relationships found. This could possibly be clarified with further analysis which would also predict emotion processing from emotion recognition and determine the stronger predictor.

5.3.1 Hemispheric asymmetry and aging

It would be important to explore these links between hemispheric processing and task performance throughout the lifespan and not restrict our understanding to what is happening in childhood. The research thus far considered not only the right hemisphere lateralisation development for emotion processing across childhood, but also the variations in the strength of lateralisation of three different emotions with development. It is also known that hemispheric asymmetry in emotion processing fluctuates in adulthood. Specifically, researchers have shown that while right hemisphere lateralisation for facial emotion processing develops and reaches a plateau by 10 years of age, in late adulthood the strength of lateralisation declines. For instance, Failla et al. (2003) reported a RH advantage for 5- to 7-year-olds, 10- to 12-year-olds and 20- to 30-year-olds, but not in the 60- to 70-year-olds. Two main models attempt to explain lateralisation changes in later life: the right hemi-aging model and the hemispheric asymmetric reduction in older adults (HAROLD) model.

The right hemi-aging model proposes that the right hemisphere shows greater age-related decline than the left hemisphere. Goldstein and Shelly (1981) showed that processes that are attributed to the RH are more affected by aging. They tested 20- to 70-year-olds on a wide range of cognitive tests, and then analysed LH tasks (e.g., language processing) and RH tasks (e.g., spatial processing). Elderly participants tended to be less proficient at tasks that were primarily processed in the RH rather than tasks that were primarily processed in the LH. This model was further tested by McDowell et al., (1994) in the emotion processing domain. They compared emotional and neutral facial recognition performance in young and elderly participants and found that older participants showed a deficit in the perception of negative emotions when compared to younger participants but were as accurate as them in identifying happy faces. Whilst this evidence was used to suggest that the RH ages more rapidly than the LH within the valence hypothesis context, Cherry et al. (1995) showed comparable hemispheric asymmetries in younger and older participants in a facial emotion recognition task for both positive and negative emotions. Overall, despite some evidence supporting the idea that the right hemisphere functions are affected more than the LH functions in the elderly the model did not find consistent support (Dolcos et al., 2002).

HAROLD model: Asymmetry Reduction in Older Adults.

In contrast to the hemi-aging model, the HAROLD model (Cabeza, 2002; Dolcos et al., 2002) rejects the idea that aging in late adulthood affects one hemisphere more than the other. Rather, the HAROLD model proposes that there is a more general reduction in asymmetry, with bilateral changes in later life.

A number of studies lend support to the HAROLD model. In the case of episodic memory retrieval, right hemisphere prefrontal cortex (PFC) activity in young adults resulted in bilateral processing over the PFC in older adults In the case of episodic encoding/semantic retrieval, left lateralised PFC activity in young adults decreased, as the right PFC activity increased (Cabeza, et al., 1997). In the case of working memory, age-related changes tended to have an increase in activation in the hemisphere that was less activated in younger adults (Reuter-Lorenz et al., 2000). Finally, a more recent study by Grady, McIntosh, Horwitz, and Rapoport (2000) reported age-related asymmetry reductions during face matching.

The age asymmetry reduction, according to Cabeza (2002), serves compensation and has a dedifferentiation function, both of which are supported by empirical evidence. The compensation view suggests that there is an increased bilaterality with age that plays a compensatory role for increasing neurocognitive deficits with age. The dedifferentiation view posits that the cognitive differentiation and neural specialisation which develops across childhood is reversed by a process of functional dedifferentiation during aging, which results in a difficulty in recruiting specialised neural mechanisms. Dedifferentiation, therefore, could be described as having more widespread neural activation patterns. Evidence for increasing correlations between different cognitive measures and correlations between cognitive and sensory measures with age was obtained by Baltes and Lindenberger (1997). In fact, they found the correlations between five cognitive measures to increase form .37 in a group of younger adults to .71 in a group of older adults. In that sense, it has been argued, dedifferentiation is part of the compensatory mechanism of an aging brain (Cabeza, 2002).

Evidence from studies with patients with unilateral brain damage (mainly from stroke) showed that recovery of a brain function in the affected hemisphere involves recruitment of homologous regions from the intact hemisphere (Cicinelli et al., 1997; Coolican et al., 2008; Gao et al., 1999; Silvestrini et al., 1998). For instance, an fMRI study by Gao et al. (1999) showed that after a left hemisphere stroke aphasic patients who had bilateral activations showed a better language recovery. Support for this view comes also from studies with normal older adults who showed that bilateral activation is associated with improved cognitive performance; in fact bilateral prefrontal cortex (PFC) activity was found to correlate with faster performance in a verbal working memory task (Reuter-Lorenz et al., 2000). More recently, Cabeza. et al. (2002) showed that the reduction in lateralisation is a compensatory mechanism for the loss of plasticity, whereby the changes in lateralisation enable more efficient cognitive processing by other areas in the brain. In a PET (positron emission tomography) study, Cabeza et al. (2002) compared patterns of activation during a memory task in three age groups: a younger adults control group, high-performing older adults, and low-performing older adults. They found that the younger participants showed a clear pattern of lateralisation, as did the low-performing older adults. However, the high-performing older adults, who were behaviourally indistinguishable from the younger adults, showed more asymmetric patterns of activation.

The interesting underlying point raised by the HAROLD model is an on-going interplay between brain and behaviour with age that is associated with changes in the brain. This makes the research undertaken in this thesis a significant contributor of unfolding and understanding the interplay between brain and behaviour for emotion processing in middle childhood.

5.4 Conclusions

In summary, this thesis aimed to explore how behavioural findings in emotion processing are mapped in the brain. Primarily it aimed to explore the electrophysiological patterns of activation in children and to assess the relationship of the development of hemispheric asymmetry for emotion processing with the development of different facial emotion recognition skills. These aims were examined with in four studies, two of which used an EEG paradigm, and two of which were behavioural studies (one longitudinal and one cross-sectional). There were four key findings that have enhanced our understanding of developments in children’s processing of facial expressions of emotion: 1) The CFT is an explicit test of laterality; 2) development differences in ERP activation for standard facial emotion showed a reduction of amplitudes with increasing age and laterality patterns differed between the children in middle childhood, children in late childhood, and adults; 3) children's facial emotion recognition development varies depending on the emotion, the intensity, and task; 4) there is an association between the development of laterality and children's developing ability to accurately match facial expressions. These four primary findings were discussed with reference to our current understanding and theoretical framework regarding neuropsychological development in the development of emotion recognition skills.

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