SOCIAL PROCESSING, FRONTAL ASYMMETRIES AND THE EFFECT OF EMOTION BASED DISORDERS UPON BRAIN FUNCTIONING AND BEHAVIOUR IN INFANCY.

By

Katharine Anne Graham

A thesis submitted to the College of Life and Environmental Sciences of the
University of Birmingham for the degree of
DOCTOR OF PHILOSOPHY

School of Psychology
College of Life and Environmental Sciences
The University of Birmingham
October 2013

ABSTRACT

This thesis had three main aims, firstly to explore the experience of auditory social and non-social stimuli upon infants brain functioning. Secondly to explore the role of the prefrontal cortex (PFC) in social and non-social visual processing and anxiety. Lastly, to investigate the effect of a mother's depression upon infant behaviour. Chapter 1 explored the literature revolving around social and non-social processing in infancy, the role of the prefrontal cortex (PFC) and the effect of depression upon mother-infant interactions and brain functioning. Chapter 2 described the methods used within this thesis. Chapter 3 investigated the impact of speech and non-speech processing upon infant brain functioning. Social and non-social processing in the PFC in infancy was explored in chapter 4. Chapter 5 looked at the impact of a mother’s anxiety upon infant frontal asymmetries. Meta-analyses were conducted in Chapter 6 to investigate differences in behaviour in the still-face paradigm between infants of depressed and infants of non-depressed mothers. Chapter 7 summarised the results of the thesis in terms of findings, implications of the results, directions for future work and limitations of the current thesis.

For Mum and Dad

ACKNOWLEDGEMENTS

Firstly, I would like to take this opportunity to thank my supervisors Joe McCleery and Jackie Blissett for their support, guidance and patience throughout my Ph.D. Thank you to my brothers, Christopher, Matthew and Simon for always making me laugh and knowing how to cheer me up. A special thank you also to their partners, Emma, Heather and Jill for being there for me and helping me keep my sanity. The most important thank you is for my parents, Katrina and Peter. Mum and Dad, I cannot express how much your endless support over these past years has meant to me, without you guys I would not have been able to do it. And thanks in advance to Dad for insuring me on your car!

Kat, Sissy, Dimitris, Giacomo, Matt, Elise, Eliza, Maria, Dicle, Chrisa, Aidan, Shannon, Leigh, Rob, Emma, Katie, Bryony, Emily, Jim and the Birmingham Law lot-simply THANK YOU! Each and every one of you means a lot to me and are a constant source of entertainment!!!

A final thank you to all the mothers and infants who took part in my research, this thesis would not have been possible without you.

TABLE OF CONTENTS

CHAPTER 1 1

GENERAL INTRODUCTION.. 1

1.1. Auditory social and non-social processing 3

1.1.2. Infant preference for speech over non speech 3

1.1.3. Infant preference for infant directed speech 5

1.1.4. Infant preference for maternal voice 6

1.1.5. Infant speech processing 7

1.1.6. Recognition of familiar words..................... 7

1.1.7. Infant recognition of native language..................... 8

1.1.8. Speech activation in the infant brain 10

1.1.8.1 Infant understanding of words and the brain 12

1.2. Visual social and non-social processing 14

1.2.1. Infant preference for social stimuli 14

1.2.2. Atypicalities in social and non-social attention..................... 15

1.2.3. Neural responses to social and non-social objects 16

1.2.4. Infant preference for the face 19

1.2.4.1. Infant preference for the female face................................... 21

1.3. The Prefrontal Cortex..22

1.3.1. Executive functions 23

1.3.1.1. Working memory.. 23

1.3.1.2. Decision Making and Reward Behaviours 26

1.3.2. Personality traits 27

1.3.2.1. Emotion Regulation 28

1.3.2.2. Infant temperament... 29

1.3.2.3. Approach/Withdrawn personalities 31

1.4. Emotion based disorders 33

1.4.1. Emotion based disorders and frontal asymmetries............................ 34

1.4.2. Emotion based disorders and the HPA axis 34

1.4.3. Depression 37

1.4.3.1. Differences in maternal behaviour....................................... 38

1.4.3.2. Differences in infant behaviour 39

1.5. Chapter outline 40

CHAPTER 2 42

GENERAL METHODOLOGY 42

2.1. Introduction to the general method chapter 43

2.2. Participant Recruitment 43

2.2.1. Recruitment for the chapters 3, 4 and 5 43

2.2.2. Recruitment for chapter 5 44

2.2.3. Inclusion and exclusion participant criteria 45

2.3. EEG 46

2.3.1. Advantages of EEG 46

2.3.2. Limitations of EEG 47

2.3.3. Event Related Potentials 49

2.4. Chapters 4 and 5 methodology 49

2.4.1. Stimuli 50

2.4.2. Procedure 51

2.4.3. EEG Recording 52

2.4.4. Data Analysis 53

2.4.4.1. Frontal EEG asymmetry calculation 54

2.5. Statistical analysis 55

CHAPTER 3 56

SPEECH AND NON-SPEECH PROCESSING IN INFANTS 56

3.1. ABSTRACT 57

3.2. INTRODUCTION 58

`3.3. METHOD 68

3.3.1. Participants 68

3.3.2. Stimuli 69

3.3.3. Procedure 71

3.3.4. EEG Recording 72

3.3.5. Electrodes 73

3.4. RESULTS 75

3.4.2. ERP Components 75

3.4.3. Frontal-Central P200 analysis 75

3.4.3.1. Test of Normality 75

3.4.3.2. 2-way ANOVA for P200 stimulus by repetition interaction . 77

3.4.3.3. Left-frontal-central P200 79

3.4.3.4. Centre-frontal-central P200 80

3.4.3.5. Right-frontal-central P200 81

3.4.4. P200 Latency Component 82

3.4.4.1. Test of Normality.. 82

3.4.5. P500 Frontal-Central 83

3.4.5.1. Test of Normality.. 83

3.4.5.2. 2-way ANOVA for P500 stimulus by repetition interaction . 84

3.4.5.3. Left-frontal-central P500 86

3.4.5.4. Centre-frontal-central P500 87

3.4.5.5. Right-frontal-central P500 88

3.4.6. P500 Temporal Component... 89

3.4.6.1. Test of Normality.. 89

3.4.6.2. Left Temporal P500... 92

3.4.6.3. Right Temporal P500... 92

3.5. DISCUSSION 95

CHAPTER 4 102

SOCIAL AND NON-SOCIAL PROCESSING IN INFANCY 102

THE EFFECT OF MOTHERS ANXIETY SYMPTOMS UPON INFANT BRAIN FUNCTIONING 102
4.0. CHAPTER 4 OUTLINE 103
CHAPTER 4 104
PART ONE 104
4.1. SOCIAL AND NON-SOCIAL PROCESSING IN INFANCY 104
4.1.1. ABSTRACT 105
4.1.2. INTRODUCTION 107
4.1.2.1. Prefrontal Cortex 107
4.1.2.2. Frontal Asymmetries 108
4.1.2.2.1 Emotion Regulation 109
4.1.2.2.2. Social Approach 110
4.1.2.2.3. Joint Attention 111
4.1.2.2.4. Temperament 112
4.1.2.3. Gender 113
4.1.2.4. Social Processing Circuits (OFC and DLPFC) 114
4.1.2.5. Aims and hypotheses 117
4.1.3. METHOD 119

4.1.3.1. Participants 119

4.1.3.2. Questionnaires 120

4.1.3.3. Electrodes 121

4.1.3.3.1. Dorsolateral Prefrontal Cortex.. 121

4.1.3.3.2. Orbitofrontal Prefrontal Cortex 122

4.1.4. RESULTS 123

4.1.4.1. Test of Normality 123

4.1.4.2. 4-Way mixed ANOVA 124

4.1.4.3. Orbitofrontal mixed ANOVA 128

4.1.4.4. Dorsolateral mixed ANOVA 130

4.1.4.5. 2-Way ANOVA for males 131

4.1.4.6. 2-Way ANOVA for females 131

4.1.4.7. 2-Way ANOVA for non-social condition 132

4.1.5. DISCUSSION 135

CHAPTER 4 142

PART TWO 142

4.2. THE EFFECT OF MOTHERS ANXIETY SYMPTOMS UPON INFANT BRAIN FUNCTIONING 142

4.2.1. ABSTRACT 143

4.2.2. INTRODUCTION 144

  4.2.2.1. Maternal Anxiety 144

  4.2.2.2. Infants of Anxious Mothers 145

  4.2.2.3. Behaviour and frontal asymmetries 147

  4.2.2.4. Frontal asymmetries, anxiety and depression 148

  4.2.2.5. Aims and hypotheses 150

4.2.3. METHOD 153

  4.2.3.1. Participants 153

  4.2.3.2. Measures 154

  4.2.3.3. Electrodes 155

4.2.4. RESULTS 157

  4.2.4.1. Multiple Regression Analysis Dataset Diagnostics 157

    4.2.4.1.1. Outliers 158

    4.2.4.1.2. Collinearity 158

    4.2.4.1.3. Independent Errors 158

    4.2.4.1.4. Random Normally Distributed Errors 159

4.2.4.1.5. Linearity and Homoscedasticity 159

4.2.4.1.6. Non-Zero Variances... 159

4.2.4.2. Prediction of frontal asymmetries using hierarchical multiple regression analyses 160

4.2.4.2.1. Prediction of frontal asymmetry for the Non-Social condition 160

4.2.4.2.2. Prediction of frontal asymmetry for the Social condition 162

4.2.5. DISCUSSION 164

CHAPTER 5 170

META-ANALYSIS: DEPRESSION AND THE STILL-FACE PARADIGM 170

5.0 RATIONALE 171

5.1. ABSTRACT 173

5.2. INTRODUCTION 174

5.3. METHOD.. 181

5.3.1. Selection of studies.. 181

5.3.2. Meta-analytic Procedures 183

5.3.3. Meta-analysis 1: The Still-Face Effect in infants of non-depressed mothers 183

5.3.3.1. Collapsing behaviours 184

5.3.3.2. Random effects model 184

5.3.4. Meta-analysis 2: Direct comparison of behavioural changes across episodes 185

5.3.5. Meta-analysis 3: Direct comparison of behaviour for each episode 185

5.4. RESULTS 188

5.4.1. Meta-Analysis 1 188

5.4.2. Meta-Analysis 2 192

5.4.3. Meta-Analysis 3 192

5.5. DISCUSSION 194

CHAPTER 6 199

GENERAL DISCUSSION 199

6.1. Thesis aims and overview 200

6.2. Summary and interpretations of findings 202

6.2.1. Chapter 3 203

6.2.2. Chapter 4 Part 1 203

6.2.3. Chapter 4 Part 2 204

6.2.4. Chapter 5 205

6.3. Integration with previous context 205

6.3.1. Chapter 3 206

6.3.2. Chapter 4 Part 1 208

6.3.3. Chapter 4 Part 2 210

6.3.4. Chapter 5 211

6.4. Implications of results and future directions 213

6.4.1. Chapter 3: Speech and non-speech processing in infants...213

6.4.2. Chapter 4 Part 1: Social and non-social processing in infancy 214

6.4.3. Chapter 4 Part 2: The effect of mothers anxiety symptoms upon infant brain functioning...216

6.4.4. Chapter 6: Meta-analysis: depression and the still-face paradigm...217

6.5. Limitations 219

6.6. Conclusion 224

APPENDIX 226

Demographic Questionnaire...227

HAD Scale 229

REFERENCES 233

TABLE OF FIGURES

Figure 2.1. Non-Social Condition 51

Figure 2.2. Social Condition 51

Figure 3.1. Left-frontal-central electrodes 73

Figure 3.2. Central-frontal-central electrodes 73

Figure 3.3. Right-frontal-central electrodes 74

Figure 3.4. Temporal electrodes 74

Figure 3.5. P200 Speech vs Non-Speech frontal-central 77

Figure 3.6. P200 Matach and Mismatch waveforms frontal cortex 78

Figure 3.7. P200 Speech vs Non-Speech left-frontal-central 79

Figure 3.8. P200 Speech vs Non-Speech central-frontal-central 80

Figure 3.9. P500 Speech vs Non-Speech frontal-central 85

Figure 3.10. P500 Speech vs Non-Speech left-frontal-central 87

Figure 3.11. P500 Speech vs Non-Speech Temporal Region 90

Figure 3.12. Match and Mismatch waveforms temporal cortex 91

Figure 3.13. P500 Speech vs Non-Speech, Match vs MisMatch Temporal Region 93

Figure 4.1.1. F3 electrodes 121

Figure 4.1.2. F4 electrodes 121

Figure 4.1.3. Left Orbitofrontal electrodes 122

Figure 4.1.4. Right Orbitofrontal electrodes 122

Figure 4.1.5. PSD values for the OFC and DLPFC 124

Figure 4.1.6. PSD values for the left and right hemispheres. 125

Figure 4.1.7. PSD values for significant interaction of hemisphere by condition. 126

Figure 4.1.8. PSD values for left and right hemispheres in the OFC. 128

Figure 4.1.9. PSD values for a marginally significant interaction of hemisphere by condition. 129

Figure 4.1.10. PSD values for significant interaction of hemisphere by condition for females. 132

Figure 4.1.11. PSD values for significant interaction of gender by hemisphere in the non-social condition. 133

Figure 4.2.1 F3 Electrodes 156

Figure 4.2.2. F4 electrodes 156

Figure 4.2.3. Participant by HADS scores 157

Figure 4.2.4. Mean asymmetry PSD values for male and females in the non-social condition. 161

Figure 5.1. PA from baseline to still-face episode 188

Figure 5.2. PA from baseline to reunion episode 189

Figure 5.3. NA from baseline to still-face episode 190

Figure 5.4. NA from baseline to still-face episode 190

Figure 5.5. NA from baseline to reunion episode 191

Figure 5.6. PA displayed at still-face episode. 193

INDEX OF TABLES

Table 3.1. Average amount of viable trials included, for each condition with standard deviations (SD) 69

Table 3.2 Shapiro-Wilk p-values for the P200 speech and non-speech data by hemisphere and repetition for the frontal-central region. 76

Table 3.3. Shapiro-Wilk p-values for the P200 speech and non-speech latency data by repetition in the frontal-central region. 82

Table 3.4. Shapiro-Wilk p-values for the P500 speech and non-speech stimuli by repetition in the frontal-central region. 83

Table 3.5. Shapiro-Wilk p-values for the P500 speech and non-speech data by hemisphere and repetition for the temporal region. 89

Table 3.6. Average amplitude values for the frontal-central P200 component, P200 latency component, P500 frontal-central and temporal component. 94

Table 4.1.1. Shapiro-Wilk p-values for the OFC and DLFC data for each condition and hemisphere by gender. 123

Table 4.1.2. Mean PSDs for OFC, DLFPC and combined regions by hemisphere, condition and hemisphere by condition 134

Table 4.2.1. Mean asymmetry scores for both social and non-social conditions by gender and in total 160

Table 4.2.2. Hierarchical regression analyses to predict infant frontal asymmetry 163

Table 5.1. Studies included in the meta-analysis, number of infants and mean age by depressed and non-depressed groups 182

Table 5.2. Studies which contributed to meta-analyses 187

CHAPTER 1

GENERAL INTRODUCTION

This thesis has three main aims, firstly to explore the experience of auditory social and non-social stimuli upon infant brain activity. Secondly to explore the role of the prefrontal cortex (PFC) in social and non-social visual processing in relation to maternal anxiety. Lastly, to conduct a systematic review of the effect of a mother's depression upon infant behaviour and affect during face-to-face interactions. Therefore, this introduction will provide a thorough overview of the relevant literature on infants' social and non-social processing, the prefrontal cortex, and the effects of maternal depression and anxiety on infant behaviour and development.

Research into infant social and emotional development has provided us with an insight into the development of language processing and infant behaviour. For instance, literature has demonstrated that from an early age infants show a preference for social stimuli over non-social stimuli (Di Giorgio, Turati, Altoe & Simion, 2012; Gliga, Elsabbagh, Andravizou & Johnson, 2009). Researchers believe that this social bias underpins infants learning capacities for areas such as language processing (Snow, 1999). Furthermore, research on infant emotional development has highlighted the importance of the frontal lobes in emotion regulation early on in life (Dawson, 1994) and the impact upon infant behaviour and brain activation as a result of having a mother with an emotion based disorder, such as depression (Diego, Field, Jones & Hernandez-Reif, 2006).

The development of infant social preferences has been examined using auditory and visual domains. For instance, auditory domains have explored infant preference for speech over non-speech (Colombo & Bundy, 1981; Shultz & Vouloumanos, 2010; Samples & Franklin, 1978; Spence & DeCasper, 1987; Vouloumanos & Werker, 2004; Vouloumanos & Werker, 2007), infant preference for infant directed speech (Cooper & Aslin, 1990;

McRoberts & Whaley, 1995; Pegg, Werker, & McLeod, 1992) in addition to infant preference for the maternal voice (DeCasper & Fifer, 1980; Kisilevsky, Harris, Lee, Xie, Huang, Ye et al., 2003), recognition of their native language (Nazzi, Jusczyk & Johnson, 2000; Nazzi, Floccia & Bertoncini, 1998; Bosch & Sebastián-Gallés, 1997), the role of speech activation in the infant brain (Dehaene-Lambertz, Dehaene, Hertz-Pannier, 2002; Peña, Maki, Kovacic, Dehaene-Lambertz, Koizumi, Bouquet, et al., 2003) and their recognition of familiar words (Halle & De Boysson-Bardies, 1996; Mills, Coffey, & Neville, 1993; Molfese, Wetzel, & Gill, 1993). Exploration of infant social preferences in the visual domain have investigated facial preferences (Johnson & Morton, 1991; Valenza, Simion, Macchi Cassia & Umilta, 1996), particularly preferences for female faces (Quinn, Uttley, Lee, Gibson, Smith, Slater, et al., 2008; Quinn, Yahr, Kuhn, Slater and Pascalis, 2002). The thesis will now move onto review the literature on social and non-social processing within the auditory and visual domains before exploring the role of the PFC and emotion based disorders.

1.1. Auditory social and non-social processing

1.1.2. Infant preference for speech over non speech

The literature has demonstrated that infants attend longer to speech in comparison to non-speech stimuli such as synthetic speech, warbled tones and white noise (Colombo & Bundy, 1981; Samples & Franklin, 1978; Spence & DeCasper, 1987). Further to this, infants have also been found to exhibit different behavioural responses to speech and non-speech stimuli (Shultz & Vouloumanos, 2010). Infants typically show a preference for speech in terms of attending to speech stimuli for longer periods of time and actually altering their sucking behaviour in order to hear speech (Shultz & Vouloumanos, 2010; Vouloumanos & Werker, 2004; Vouloumanos & Werker, 2007). Vouloumanos & Werker (2004) conducted a study with 2- to 7-month-old infants exploring their behavioural responses to nonsense speech and complex non-speech analogues. The authors found that infants from 2-months of age attended longer to speech sounds. Further work by Vouloumanos and Werker (2007) has provided supporting evidence for a very early speech bias in infants. Specifically, these researchers explored infant listening preferences for speech and complex non-speech stimuli in twenty-two 1- to 4-day-old infants. Infants were given a pacifier and were initially measured on their "resting" baseline suction on the pacifier. After the initial baseline period, infants were presented with a sound stimulus every time their suction was in the upper 80% of their sucking range. Interestingly, Vouloumanos and Werker (2007) replicated their earlier finding but this time in newborn infants. The newborn infants also displayed a bias for listening to speech as sucking amplitudes significantly increased for the speech stimuli. The authors believe this finding provides support for the viewpoint that the preference for language over non-language is innate, as even neonates are able to distinguish between speech and non-speech despite their very limited experience with language.

1.1.3. Infant preference for infant directed speech

Infant-directed speech (IDS) is a form of communication adopted by adults when interacting with infants (Singh, 2002). Fewer words are spoken with more repetitions, better articulation, and reduced structural complexity in IDS than in adult-directed speech (ADS; Cooper & Aslin, 1990). It is believed that IDS facilitates early language development in infants, developing social and attentional related functions early in life (Cooper & Aslin, 1990; Snow, 1999). Infants have also been found to have a preference for IDS from birth (Cooper & Aslin, 1990). Cooper and Aslin (1990) explored preference for IDS in newborns and 1-month-old infants. Infants were measured on length of looking at visual stimuli which were coupled with either IDS or ADS. Both newborns and 1-month-olds attended significantly longer to the visual stimuli which was coupled with ID speech. This finding suggests that infants have a preference for IDS from birth and are more sensitive to the exaggerated manner speech. Similarly, infant preference for IDS has also been found across male and female speech (Pegg, Werker, & McLeod, 1992). Pegg et al. (1992) examined infant preference for IDS over ADS in 7-week-olds when delivered by male and female speakers. The findings showed that infants discriminated between IDS and ADS, showing a bias for IDS regardless of speaker gender. Further to this, McRoberts and Whaley (1995) explored IDS and ADS in both native and non-native languages. Infant preference for IDS remained even when presented in a non-native language. Researchers have suggested that early language processing and learning capacities in infancy are facilitated by infants’ increased sensitivity towards IDS (Snow, 1999).

1.1.4. Infant preference for maternal voice

Research has revealed that foetuses are able to discriminate between their mother's voice and that of another female even in the womb (Kisilevsky, Harris, Lee, Xie, Huang, Ye et al., 2003). In one study (Kisilevsky et al., 2003) sixty foetuses were exposed to either a tape recording of their mother or of a female stranger. The study showed that foetal heart rate significantly increased in response to their own mother's voice but not to that of the stranger. Discrimination for the maternal voice has also been found in newborn infants (DeCasper & Fifer, 1980). DeCasper and Fifer (1980) explored the behavioural effect of a mother's voice on newborn infants. Infants were given a pacifier which was linked to recording equipment. Initially, cessation of sucking produced mother's voice and increased sucking produced another female voice. The direction of sucking requirements was later reversed, meaning sucking cessation resulted in hearing a random female voice and increased sucking resulted in hearing their mother's voice. The results revealed that infants were able to discriminate between their mother's voice and another female's. Further to this, the results also demonstrated a preference for the maternal voice, even when sucking requirements to hear their mother's voice were reversed, infants adapted to these new requirements in order to hear their mother's voice. Researchers believe the ability of infants and foetuses to discriminate between their own mother's voice and that of a stranger is evidence of experience influencing infant voice processing (Kisilevsky et al., 2003). Furthermore, that infants have neural networks which are sensitive to mother's voice which are even evident before birth (Kisilevsky et al., 2003).

1.1.5. Infant speech processing

Even before word production, infants are able to recognise familiar words (Halle & De Boysson-Bardies, 1996; Harris, Yeeles, Chasin & Oakley, 1995), different languages (Bosch & Sebastián-Gallés, 1997; Nazzi, Jusczyk & Johnson, 2000; Nazzi, Floccia & Bertoncini, 1998) and even distinguish differences between the more complex parts of speech such as consonants (Halle & De Boysson-Bardies, 1996) and point vowels (Polka & Bohn, 2003).

1.1.6. Recognition of familiar words

Infants who have not yet produced words appear to understand some words and short phrases in familiar situations (Halle & De Boysson-Bardies, 1996). For instance, Harris et al. (1995) conducted home visits from the age of six months to observe developing word production and comprehension in infants. Although individual differences were apparent, by 9-to-10 months of age all infants had achieved some level of word comprehension. However, it has been suggested that infants recognising words at this age may be the result of responding to the sound pattern of the word in the familiar situation as opposed to fully understanding the meaning (Menyuk & Menn, 1979). Additional studies investigating word comprehension in less familiar settings have found that infant word comprehension occurs from 11-to-13-months (Halle & De Boysson-Bardies, 1996; Mills, Coffey, & Neville, 1993; Molfese, Wetzel, & Gill, 1993). Further to this, it has been suggested that the composition of words is key to infant comprehension (Halle & De Boysson-Bardies, 1996). For example, Halle and De Boysson-Bardies (1996) explored the type of mental representations adopted by infants to aid word recognition. Infants were presented with familiar and unfamiliar words which were spoken as they should be or had their first word-initial consonant changed. Infants were measured on how many times they turned their head to attend to each word. Results demonstrated the importance of the word-initial consonant in word recognition, as infants oriented longer to familiar unaltered words as opposed to familiar altered words and unfamiliar altered/unaltered words. In addition, Polka and Bohn (2003) reviewed vowel discrimination in infants and found that infants respond differently to vowels, depending upon their position in a word. The current literature suggests that vowel discrimination plays an important role in word comprehension and speech development as vowels provide crucial reference points for word recognition.

1.1.7. Infant recognition of native language

Recognition of a language requires an individual to identify regularities which are linguistically relevant whilst ignoring other irrelevant properties such as changes in voice, amplitude and speech rate (Nazzi et al., 1998). Infants have been found to discriminate their native language from other languages (Bosch & Sebastián-Gallés, 1997; Nazzi et al., 1998; Nazzi et al., 2000). Nazzi et al. (2000) explored 5-month-old American infants ability to discriminate languages using the head turn preference procedure. Infants were presented with passages in different languages, including English, Spanish, Japanese, and Italian. Passages were played when the infant orientated to a flashing light and finished when the infant looked away. Overall, infants attended longer to English passages. Similar findings were observed in an earlier study by Bosch and Sebastián-Gallés (1997) which examined 4-month-old infants capacity to identify their maternal language when phonologically similar languages were contrasted. Despite phonological similarities between the infants native language and another, infants still showed a bias for the native language. Furthermore, in this study monolingual and bilingual infants were compared. Infants who were in a bilingual environment did not show a preference for either familiar language. However, they attended longer to both familiar languages when compared to unfamiliar languages, just like the monolingual infants. At 5-months of age, infants have acquired the knowledge of the sound organisation of their native language (Nazzi et al., 2000). Nazzi and colleagues (2000) therefore believe that these findings provide evidence for the native-language acquisition hypothesis which states that infants can discriminate their native language due to specific rhythmic features.

Literature on speech preferences has aided our understanding of language processing in infancy. For instance, the research has demonstrated that from an early age infants show a preference for speech (Spence & DeCasper, 1987; Samples & Franklin, 1978; Colombo & Bundy, 1981) and are able to recognise familiar words (Halle & De Boysson-Bardies, 1996) and distinguish between their native language and a novel one (Bosch & Sebastián-Gallés, 1997; Nazzi et al., 1998; Nazzi et al., 2000). Researchers believe that infants are born with neural networks which are sensitive to speech specifically (Kisilevsky et al., 2003) and facilitate early language development, with early speech sensitivities aiding language acquisition (Cooper & Aslin, 1990).

1.1.8. Speech activation in the infant brain

Exploration of speech processing in infancy is necessary to provide a deeper insight and understanding into the development of speech processing mechanisms in the brain. Recent literature has revealed that infants recruit different neural resources for speech and non-speech processing (Dehaene-Lambertz, Dehaene & Hertz-Pannier, 2002; Peña, Maki, Kovacic, Dehaene-Lambertz, Koizumi, Bouquet, et al., 2003). Some researchers believe that infants are born with a left hemisphere superiority for processing speech (Peña et al., 2003), with language areas being active even before the onset of speech production (Dehaene-Lambertz, et al., 2002). However, research into the neural basis of speech processing in infancy is limited and has mixed findings (Dehaene-Lambertz, et al., 2002; Vouloumanos & Werker, 2007). Left-lateralised brain regions including the superior temporal and angular gyri have been found to be activated during normal speech exposure in infancy (Dehaene-Lambertz, 2000; Dehaene-Lambertz et al., 2002; Minagawa-Kawai, Van der Lely, Ramus, Sato, Mazuka, & Dupoux, 2010). Literature has also shown activation of the right prefrontal cortex in response to speech (Dehaene-Lambertz et al., 2002; Dehaene-Lambertz et al., 2006). Some studies however, have not found a left lateralisation in infants in response to speech but bilateral activation of the temporal regions (Dehaene-Lambertz et al., 2006; Dehaene-Lambertz & Baillet, 1998; Kotilahti, Nissila, Nasi, Lipiainen, Noponen, Merilainen, et al., 2010; Pang, Edmonds, Desjardins, Khan, Trainor & Taylor, 1998). The authors believe that speech lateralisation is not yet fully developed in infants but suggest that the temporal lobe is part of a dedicated neuronal network for processing speech and is apparent from infancy.

A potential reason for differences in topography could be a result of the different neurological methods employed in these studies. For instance, studies relying upon EEG will benefit from high temporal resolution, which is the amount of neuronal activation recorded with respect to time (Neil, 2006). This means that measurements of the time course of speech and non-speech processing will be excellent. In contrast, temporal resolution is very poor in fMRI, with approximately four images per second being generated as opposed to one per millisecond in EEG (Neil, 2006). It is therefore possible that fMRI studies may not detect early or fast occurring brain activation in response to speech. Despite this disadvantage, fMRI has the advantage of high spatial resolution, which enables the potential to localise speech in the brain (Neil, 2006). As EEG relies on surface measurements of electrical brain activation, spatial resolution is very weak (Neil, 2006). This means that it is possible that the generating source of a function (e.g. speech) may be at some distance from the recording electrode. Therefore, the ability to localise speech in the brain using EEG will be extremely limited in comparison to fMRI. Despite the differences presented in each method, it is important to note that mixed findings within the literature have also been found between studies using the same neurological methods. For instance, an fMRI study conducted by Dehaene-Lambertz et al., (2002) found left-lateralisation for infants in response to speech in comparison to Dehaene-Lambertz et al., (2006) who did not find a left lateralisation but a bilateral activation of the temporal regions. Additionally, similarities in findings have also been found between studies using different neurological tools. For example, EEG, fMRI and fNIR studies have found left lateralised brain regions when infants listen to normal speech (Dehaene-Lambertz, 2000; Dehaene-Lambertz et al., 2002; Minagawa-Kawai, Van der Lely, Ramus, Sato, Mazuka, &

Dupoux, 2010). This therefore suggests that differences in topography cannot be completely attributed to the different neurological methods employed in each study.

The current findings will be discussed further in the introduction of chapter 3 (section 3.2.).

1.1.8.1 Infant understanding of words and the brain

The previous literature presented here (section: 1.1.8) has provided support for the beginnings of a neural specialisation for speech processing in infancy (Dehaene-Lambertz, Dehaene & Hertz-Pannier, 2002; Peña, Maki, Kovacic, Dehaene-Lambertz, Koizumi, Bouquet, et al., 2003). Further research has expanded upon this literature by providing electrophysiological evidence for infants' understanding of speech (Friedrich & Friederici 2004; Friedrich & Friederici, 2005; Friedrich & Friederici, 2010; Parise & Casibra, 2012). This body of research has investigated how infants' understanding of speech is reflected in the brain, by adopting event-related potential (ERP) methodologies. Previous adult ERP studies exploring speech processing have revealed an N400 component in response to the use of semantically inappropriate words in sentences (Kutas & Hillyard, 1980). This finding indicates that the individual has an understanding of the words presented, with the N400 component being a reflection of the semantic processing undertaken in response to the incorrect use/positioning of a word (Kutas & Hillyard, 1980). Similar results have been found with infant populations (Friedrich & Friederici 2004; Friedrich & Friederici, 2010; Parise & Casibra, 2012). For instant, Friedrich and Friederici (2004) conducted an ERP study whereby

19-month-old infants were presented with pictures of known objects which were either paired with congruent or incongruent words. Results revealed an enhanced N400 amplitude in the 19-month-olds to words which were not correctly matched with the pictures. Furthermore, an N400 component was found in the same context for 14-month-old infants (Friedrich & Friederici, 2005). Interestingly, in Friedrich and Friederici (2010) an N400 component was also seen in 12-month-olds, but only in infants who were assessed as high word producers, i.e. infants who had greater word-object knowledge. From these findings the authors discussed the possibility of the N400 component being related to the stage of language development a child has achieved. The absence of an N400 effect in the low word producing infants was viewed as an indication that the infants had only achieved associative word understanding which does not include semantic processing abilities. Furthermore, infants as young as 9-months have also been found to display an N400 effect. Parise and Csibra (2012) presented infants with familiar objects with either congruent or incongruent verbal labels as the previous studies had done, however, the verbal labels were either given by the experimenter or the mother. An N400 effect was only found in the conditions where the mother presented the word and was able to use different gestures to guide the infants' behaviour. The authors interpreted this finding as word learning being referential, whereby infants are able to make use of certain cues and exploit them during language acquisition.

1.2. Visual social and non-social processing

1.2.1. Infant preference for social stimuli

Research has demonstrated that from an early age infants show a preference for social stimuli over non-social stimuli (Di Giorgio, Turati, Altoe & Simion, 2012; Gliga, Elsabbagh, Andravizou & Johnson, 2009). Gliga et al. (2009) conducted an eye-tracking study to explore attention to social and non-social objects in 6-month-old infants. Infants were presented with complex visual arrays which consisted of picture of faces and non-social items such as vehicles and mechanical toys. Infant eye movements were measured, recording the direction of the first eye movement towards a face and the total number of fixations to faces. The authors found that infants were significantly more likely to attend to the social stimuli. Face stimuli captured infant attention first and maintained their attention for significantly longer than the non-social stimuli. Di Giorgio et al. (2012) also investigated infant attention to social and non-social stimuli. Infants eye movements were recorded whilst they were presented with thirty-two different visual arrays, each containing a target face and three non-social items. The results provided support for Gliga et al. (2009) as 6-month-olds showed a preference for the social stimuli. Infants showed a significantly greater number of fixations and a significantly greater total fixation time towards the faces. The authors believe that the results may reflect an early developing bias for visual information that is social in nature.

1.2.2. Atypicalities in social and non-social attention

As the previous section demonstrated, infants typically show a preference for social stimuli (Di Giorgio, Turati, Altoe & Simion, 2012; Gliga, Elsabbagh, Andravizou & Johnson, 2009). Interestingly, atypicalities in social and non-social attention during infancy have been associated with the emergence of autism spectrum disorder (ASD: Bedford, Pickles, Gliga, Elsabbagh, Charman, Johnson & BASIS, 2014; Elsabbagh, Fernandes, Webb, Dawson, Charman, Johnson & BASIS, 2013), a disorder characterised by social and communication difficulties (World Health Organization, 1993 as cited in Elsabbagh et al., 2013). Bedford et al., (2014) conducted a study exploring whether social and non-social attention during infancy could be a predictor of ASD in later life. The authors examined social and non-social attention by measuring 13-month-old infants' gaze following (social) and attentional disengagement (non-social) behaviours. Results revealed that gaze following and attentional disengagement at 13 months predicted ASD outcome. Infants who displayed atypical social and non-social responses were more likely to develop the disorder. Reductions in gaze following time in addition to slower disengagements were linked to ASD emergence in toddlerhood. This finding supported earlier work by Elsabbagh et al., (2013) who also explored the disengagement of visual attention in infancy and the association with ASD in toddlerhood. Infants who later developed ASD displayed atypical visual attention responses. Literature has suggested a link between social behaviour and visual attention, with the ability to orient to certain information in the environment enabling an individual to self-regulate their arousal and effect (Bryson, Zwaigenbaum, Brian, Roberts, Szatmari, Rombough et al., 2007). The authors therefore believe that reduced social attention could be related to the atypical development of visual attention skills in these infants, which disadvantages the child in orienting to social stimuli. In the context of the present thesis, although preferences for social stimuli are typically found in infancy (Di Giorgio, Turati, Altoe & Simion, 2012; Gliga, Elsabbagh, Andravizou & Johnson, 2009), it is important to note that atypicalities within social and non-social processing in infancy are often associated with disorders such as ASD (Bedford et al., 2014; Elsabbagh et al., 2013).

1.2.3. Neural responses to social and non-social objects

Neural responses to social and non-social stimuli have been explored using biological motion (BM) and scrambled motion (SM) (Hirai & Hiraki, 2005; Lloyd-Fox, Blasi, Everdell, Elwell & Johnson, 2011). BM refers to an individuals' ability to recognise the human form and motion from viewing an arrangement of moving light-points (Johansson, 1975). Further to this, research has shown that humans can also discriminate the gender of a light-point figure (Kozlowski & Cutter, 1977) and differentiate between familiar individuals and strangers (Cutting & Kozlowski, 1976). In contrast, SM is the random arrangement and movements of light points which do not reflect the human form (Hirai & Hiraki, 2005). Infants show different neural responses when presented with social and non-social stimuli (Hirai & Hiraki, 2005; Lloyd-Fox et al., 2011). Hirai & Hiraki (2005) explored social and non-social processing in 8-month-old infants. Infants were presented with videos of BM (social) and SM (non-social) whilst brain responses were recorded via EEG. Greater right hemispheric activation was found for BM, suggesting by 8-months there are specific neural circuits specifically for visual social processing. Further to this, Lloyd-Fox et al. (2011)

investigated brain activation differences in 5-month-old infants when presented with biological and mechanical motion. Infants were presented with videos of biological movement which consisted of adults moving their hands, mouth, and eyes. They were also presented with non-biological videos which included moving pistols, cogs, and toys. Different patterns of cortical activation were observed in the frontal and temporal cortex when an infant watched biological videos as opposed to non-biological videos. The authors attributed differences in activation as the infant brain selectively responding to the social nature of the stimuli and evidence of an early processing system for biological motion.

It has been suggested that this early processing system in infants may be a primitive neural pathway which ensures a bias for attending toward sensory information about other humans (Johnson & Farroni, 2007). From an evolutionary perspective, preferentially processing information about members of your species would give an individual an advantage in terms of survival (Johnson & Farroni, 2007). Meltzoff & Moore (1997) have proposed that infants are born with an amodal body schema which allows them to understand similarities between themselves and others. Gliga and Dehaene-Lambertz (2005) conducted an event-related potentials (ERP) study to explore the processing of the human form in infancy. The researchers presented 4-month old infants with either typical or distorted human faces or bodies. Results revealed a reduction in a P400 type component in the bilateral posterior regions when distorted bodies or faces were presented. The authors suggested that this was evidence of 4-month old infants being able to distinguish between a typical and distorted human body, meaning that infants as young as 4-months have a representation of the human form. However, behavioural research has suggested that infants may not develop expectations about the human form until the second year of life (Slaughter, Heron & Sim, 2002). Slaughter et al., (2002) investigated infant preference for human body shape in 12, 15 and 18-month old infants. Infant looking preferences were measured when they were presented with paired line drawings of typical and scrambled bodies. Interestingly, only the 18-month old infants showed a reliable preference for scrambled bodies over typical bodies, indicating that the scrambled bodies were not in line with their expectations. However, it is possible that younger infants may not have shown a looking preference as the stimuli were not realistic portrayals of the human form. Heron & Slaughter (2010) found that infants as young as 9-months were able to recognise the typical human form but recognition was dependent on the realism of the stimuli presented. For instance, infants were able to distinguish between typical and scrambled forms when real body parts were used.

This body of research suggests that an innate neural circuitry for social processing is present in infants, as they are able to detect BM from point light displays (Hirai & Hiraki, 2005; Lloyd-Fox, Blasi, Everdell, Elwell & Johnson, 2011) and can distinguish between typical and scrambled human body forms (Heron & Slaughter, 2010; Slaughter et al., 2002). However, the development of this circuitry may be influenced by an infant’s experiences. Younger infants are able to distinguish between scrambled and atypical bodies but only when they have when realistic representations of body parts are displayed (Heron & Slaughter, 2010), in contrast to 18-month-old infants who can detect differences from line drawings (Slaughter et al., 2002). As the type of stimulus presented to an infant can affect their performance (Heron & Slaughter, 2010), younger infants may require more detailed cues to be able to differentiate between social information.

1.2.4. Infant preference for the face

The ability to recognise faces is an important social adaptation as it provides a wealth of socially relevant information (Grossmann, 2007). Typically, infants' earliest social experiences consist mainly of face-to-face interactions, giving infants an abundance of opportunities to learn about faces (Pascalis, de Schonen, Morton, Deruelle & Fabre-Grenet, 1995). However, newborn infants, with limited social experiences show a preference for attending to human faces and face-like patterns (Johnson & Morton, 1991; Valenza, Simion, Macchi Cassia & Umilta, 1996). Johnson and Morton (1991) explored tracking behaviour in infants when presented with face-like stimuli. Infants were placed on their back and were shown three head shaped boards. One board had face-like features on it (eyes, nose and mouth etc.), the second also had face-like features, but the order of the features were scrambled and the third board was left blank. Each board was presented to the infants individually, as soon as the infant fixated on the board it was then moved in an arc shape around the child. Infants were measured on the length of time they fixated on each board and how far they turned their head when following the stimuli. Results revealed that infants significantly tracked the face-like board further and longer than the scrambled or the blank board. The authors suggest that newborn infants have a preference for face-like configurations and this finding has been replicated in further studies (Johnson, Dziurawiec, Ellis & Morton, 1991; Morton & Johnson, 1991; Valenza et al., 1996). Further research has suggested infants are only able to discriminate between face-like stimuli after 2-months of age (Maurer & Barrera, 1981). Maurer and Barrera (1981) presented 1-month old and 2-month old infants with typical faces and scrambled faces. Only the 2-month old infants looked longer at the typical face, the authors interpreted this finding as the older infants being able to discriminate between the two, despite both displaying facial features.

As evident from the above literature, newborn infants will only show a preference for face-like patterns (Johnson & Morton, 1991) and it is not until 2-months of age when an infant will discriminate between two face-like patterns (Maurer & Barrera, 1981), suggesting the development of a more sophisticated visual system. It is believed that a complex perceptual system is present at birth which aids the recognition of social stimuli (Johnson and Morton, 1991). Morton and Johnson (1991) proposed a two-process theory of infant face recognition, referred to as the CONSPEC-CONLERN theory. The CONSPEC mechanism refers to an innate mechanism which guides the initial infant preference for face-like patterns. The CONLERN mechanism however, is a system which allows the infant to learn more about the visual characteristics of the face but does not influence behaviour until 2-months of age. This model has received criticism from authors who have demonstrated that the positioning of facial features does not impact infant preference (Cassia, Turati & Simion, 2004). Cassia et al (2004) found that newborn infants had a general preference for “top-heavy” stimuli, even if facial features were not present. Cassia and colleagues (2004) argue that newborn infants do not have a facial preference or an innate CONSPEC mechanism as Morton and Johnson (1991) propose but instead an upper-visual-field sensitivity which drives the facial preference. Despite this criticism, researchers believe that infant facial preference provides evidence of a powerful mechanism in the newborn brain existing with a bias for social input (Grossmann & Johnson, 2007). Furthermore, the initial upper-visual-field sensitivity could be evidence of the CONSPEC mechanism, as this bias may have evolved specifically for face processing (Gliga & Csibra, 2007).

1.2.4.1. Infant preference for the female face

Quinn, Yahr, Kuhn, Slater and Pascalis (2002) explored infant representations of gender in 3 to 4-month-old infants. Infants were placed on their parents lap and were presented with pictures of men and women. The researcher observed the infants and measured the number of visual fixations towards each picture. Prior to this picture presentation all infants had been familiarised with pictures of either the men or women. The results revealed an infant preference for female faces. Even when infants had been familiarised with the males faces prior to the experiment, infants still fixated on a novel female face for longer. Additionally, when an infant had been familiarised with female faces, their attention was split between novel male and female faces. The authors believe these findings suggest a spontaneous bias for the female face. Quinn and colleagues (2002) also explored the effect of the gender of the primary caregiver on infant face preference. When infants were raised by a female caregiver, they showed a preference for the female faces. Interestingly, when infants had a male primary caregiver, they showed a spontaneous preference for male faces. Further studies have also found a female face preference in infants (Quinn, Uttley, Lee, Gibson, Smith, Slater, et al., 2008). Quinn et al. (2008) explored gender facial preference across different races. 3-month old Caucasian infants showed a female over male face preference when adult Caucasian faces were presented. However, this gender preference was not found when Asian adult faces were displayed. Both these findings suggest that the processing of human faces in infants is influenced by the gender and race of the primary caregiver (Quinn et al., 2002; Quinn et al., 2008). Infant experience of their primary caregiver appears to play a crucial role in early infant facial preference.

In summary, research has shown that infants have a preference for social stimuli over non-social stimuli (Gliga et al., 2009; Giorgio et al., 2012), with authors suggesting that infants have a bias for visual information that is social in nature (Gliga et al., 2009). Evidence has also been presented for an early processing system which selectively responds to social stimuli (Lloyd-Fox et al., 2011; Morton and Johnson, 1991). Infant facial preferences have also been found to change with age. For instance, newborns show a preference simply for faces over non-faces (Johnson et al., 1991; Valenza et al., 1996) but by 3-months of age infants have developed a preference for the type of face presented to them, showing a bias which reflects the gender and race of their primary caregiver (Quinn et al., 2002; Quinn et al., 2008). This body of research therefore illustrates how infants early social experiences can start to shape their behaviour. Now that the literature on social and non-social processing in auditory and visual domains has been reviewed, the thesis will now move onto explore the role of the PFC in social processing and cognition.

1.3. The Prefrontal Cortex

The Prefrontal Cortex (PFC) is the largest of all the brain lobes in humans and primates (Buchsbaum, 2004) and is positioned at the anterior pole of the mammalian brain. The PFC plays a critical role in important cognitive functions (Miller & Cohen, 2001). It is strongly associated with executive functions such as working memory and decision making, which play a fundamental support role in social cognition (Fellows & Farah, 2005; Meyer &

Lieberman, 2012; Rushworth, Noonan, Boorman, Walton & Behrens, 2011). Additionally, the PFC is coupled with individual trait differences, such as emotion regulation (Davidson, Ekman, Saron, Senulis & Friesen, 1990; Dawson, Panagiotides, Klinger & Hill, 1992), temperament (LoBue, Coan, Thrasher & DeLoache, 2011) and approach and withdrawn behaviours (Dawson, 1994; Davidson et al, 1990; Field & Diego, 2008).

1.3.1. Executive functions

Executive functions refer to higher order mental processes such as cognitive control, which includes the ability to coordinate thought and action, which the prefrontal cortex (PFC) is said to play an important role in (Miller & Cohen, 2001). Executive functions cover a broad range of behavioural areas including working memory and decision-making and reward behaviours which are explored further here.

1.3.1.1. Working memory

Working memory (WM) is the representation of new information and information retrieved from long-term memory (Curtis & D’Esposito, 2003). It is required for accessing memories (Rodriguez & Paule, 2009) in addition to being involved in the maintenance and manipulation of information (Mars & Grol, 2007). WM relies on an executive controller to supply auditory and visual information through interactions with short-term and long-term memory stores (Curtis & D’Esposito, 2003). During social interactions, mentalising is required (Meyer & Lieberman, 2012) which is the ability to think about others intentions, beliefs and mental states (Frith & Frith, 2003). Mentalising therefore depends upon WM, in order to form a conclusion about the social situation the individual must be able to access, maintain and manipulate information about themselves and others involved (Meyer & Lieberman, 2012).

Neuroimaging studies have found that the PFC is crucial for WM (Baker, Rogers, Owen, Frith, Dolan, Frackowiak & Robbins, 1996; Curtis & D'Esposito, 2003), more specifically the dorsolateral prefrontal cortex (DLPFC; Curtis & D'Esposito, 2003). The DLPFC is believed to play a role in directing attention to internal representations of sensory and motor information (Curtis & D'Esposito, 2003). Several studies have found that DLPFC activation is directly linked to WM (Baker, et al., 1996; Belger, Puce, Krystal, Gore, Goldman-Rakic & McCarthy, 1998; Courtney, Ungerleider, Keil & Haxby, 1997). It is debated however, whether the DLPFC is involved in the maintenance of information stored in WM or if it is in fact responsible for response sections within WM (Rowe, Toni & Josephs, 2000). In a study by Rowe at al. (2000) participants took part in a delay-response task to access WM whilst undergoing an fMRI. Participants were tasked to remember three spatial locations for different items for eighteen seconds. After this time they were asked to identify the correct location for one of the items based on memory. Results revealed that prefrontal areas were activated during the maintenance of information however, the DLPFC was only activated when participants had to select between different items during the WM task. Therefore Rowe et al. (2000) concluded that the DLPFC has a specific role in WM; specifically in the selection of representations. Similarly, Pochon et al. (2001) provided supporting results, and also found that DLPFC activation was greater when a response was selected at the beginning of the delay interval.

Working memory is also important for infants and children as it prepares them for social experiences by allowing them to attend and discriminate between multiple sources of information (Hoskyn, 2010). Literature on the emergence of working memory in infants and young children is not well understood (Hoskyn, 2010), furthermore neuroimaging research comparing brain activation between adults and children is limited (Klingberg, 2006). In an EEG study conducted by Bell and Wolfe (2007), brain activation was measured in 53 8-month old infants whilst they performed a task requiring working memory (A-not-B task). EEG measurements were also recorded for 43 of these infants at 4 years of age whilst they performed another task of working memory (Day-Night Stroop task). The authors found that the 8-month old infants had widespread brain activation during the working memory task but at 4 years, brain activation became increasingly localised to the prefrontal cortex. Bell and Wolfe (2007) concluded that brain regions involved in working memory become more localised as the child develops. However, an fMRI study conducted by Kaldy and Sigala (2004) found that by 6.5 months, ventrolateral and dorsolateral brain regions are employed by infants in simple tasks of working memory. Furthermore, by the first year, EEG activity in these regions has also been found to increase during working memory tasks (Cowan, 1995). Despite the limited neuroimaging research on working memory and infancy, the preliminary studies suggest the recruitment of brain regions similar to those seen in adults (Hoskyn, 2010).

1.3.1.2. Decision Making and Reward Behaviours

The prefrontal cortex has been identified as having a distinct role within reward-guided behaviour and decision making (Fellows & Farah, 2005; Rushworth, et al., 2011). Studies have found that individuals with ventromedial damage suffer from decision-making impairments (Bechara, Dolan, Denburg, Hindes, Anderson & Nathan, 2001; Fellows & Farah, 2005; Waters-wood, Xiao, Denburg, Hernandez & Bechara, 2012). Individuals with damage to the ventromedial prefrontal cortex (VMPFC) are prone to impulsive decision-making in real life and in laboratory based situations (Bechara, Damasio, Damasio & Anderson, 1994; Fellows & Farah, 2005). The majority of studies exploring decision-making impairments have used the Iowa gambling task (IGT). This measure is deemed as sensitive in detecting decision making impairments. It simulates real life decisions as it factors in uncertainty, reward and punishments into decision-making. The IGT involves participants playing a card game, selecting cards from one of four decks with the aim of winning money. Two decks are deemed as risky decks as they are associated with big wins but also big losses. In contrast, the remaining two decks are associated with smaller wins but also smaller losses. As the game develops, typical participants learn to opt for the less risky decks in order to secure a long term larger win. However, the opposite is found for participants with VMPFC damage (Bechara et al., 1994). Bechara and colleagues (1994) found participants with VMPFC damage regularly opted for the riskier decks. The authors believed that these patients were unable to see the future consequences of their actions and were only guided by the prospect of an immediate win within the task. In addition, Bechara, et al. (2001) explored the impact of substance abuse on decision-making abilities. Individuals who are deemed as substance dependent are believed to have a dysfunctional VMPFC. In this study, forty control participants, five individuals with ventromedial damage and forty-one substance dependants participated. Individuals in the substance dependent group met criteria for dependence with either alcohol or stimulants. All participants took part in the IGT. Results revealed that performance on the gambling task was predicted by several factors including years of substance abuse and number of relapses whilst in recovery. The authors explained this finding as impairments in decision-making being linked with dysfunctions in the VMPFC.

Additionally, VMPFC impairments are believed to be irreversible (Waters-wood, et al., 2012). Water-woods et al. (2012) conducted a study with patients with VMPFC damage to determine whether impairments in decision-making were stable over time or whether recovery of function over time was possible. Patients with VMPFC damage and a control group of participants had a regular administration of the IGT over six years. The control group showed repeated improvement due to practice effects. In contrast, the VMPFC group's performance on the task remained impaired without improvement. As a result, it is believed that VMPFC impairments in decision-making are not subject to autonomous recovery.

1.3.2. Personality traits

Frontal EEG asymmetries show the difference in power between the right and left frontal hemispheres. Research on personality traits is indicative of how asymmetry patterns in the PFC can start to show individual differences in trait tendencies (see Chapter 2, METHOD, section 2.4.4.1. for further information on frontal asymmetries). For example, frontal asymmetries can be suggestive of how an individual will regulate their emotions (Davidson et al., 1990; Dawson et al., 1992), what kind of temperament they will display (LoBue et al., 2011) or how they will react to an emotionally stressful stimulus (Davidson et al, 1990; Dawson, 1994; Field & Diego, 2008) i.e. whether they will display approach or withdrawal behaviours.

1.3.2.1. Emotion Regulation

The frontal lobes play a key role in the regulation of emotion with different aspects of emotions being associated with different patterns of frontal electroencephalography (EEG) activity in both infants and adults (Dawson, 1994). Dawson et al., (1992) explored the role of frontal lobe function in infant emotion regulation using EEG. 21-month-old infants were sat in a high chair and participated in various conditions which were designed to encourage different emotional responses. For example, bubbles were blown from behind a black curtain to elicit a positive emotion and the mother left the room to elicit a negative emotion. Dawson et al., (1992) found that different emotional states were associated with increased differential activation of the right and left frontal brain regions. Emotions such as happiness and sadness were associated with increases in frontal lobe activation. Sadness was associated with greater right frontal brain activity whereas happiness was associated with greater left frontal brain activity. In addition, they found emotions were lateralised in terms of positivity or negativity but not in terms of the specific emotion. If the emotion was a negative emotion, for example anger or sadness, this would always be associated with greater right frontal activation. In contrast positive emotions such as happiness were associated with greater left frontal activation. Similarly, Davidson et al., (1990) conducted an EEG study with thirty-seven adult women participants to explore how different emotions affect frontal EEG asymmetry. Participants were shown sixty second film clips which were designed to elicit positive and negative emotions such as high levels of happiness, amusement, disgust, fear, pain and sadness. The results indicated that frontal lobe asymmetries were determined by the direction of the emotions i.e. whether they were approach or withdrawal emotions. Various researchers support these findings as they believe that emotions coupled with approach towards the external environment are reflected in greater left frontal activation, whereas emotions associated with withdrawal, for example sadness are accompanied by greater right frontal activation (Davidson et al., 1990; Fox & Davidson, 1987; Wheeler, Davidson & Tomarken, 1993). These findings demonstrate how frontal asymmetries in infants and adults can start to show individual differences in emotion regulation. For example, how an individual will react to an emotionally stressful stimulus (Dawson, 1994) i.e. whether they will display approach or withdrawn emotion to particular stimuli.

1.3.2.2. Infant temperament

Temperament is thought to provide the basis for social and emotional development as it represents individual differences in response styles that remain relatively stable over an individual's life (Henderson, Fox & Rubin, 2001; Rothbart & Derryberry, 1981). Infant temperament is argued to appear early in life and to play a significant role in the expression of social behaviour (Fox & Henderson, 1999). Calkins, Fox and Marshall (1996) explored infant affective state in relation to motor activity, inhibition and frontal EEG activation in 9-month old and 14-month old infants. Infants were classes as either high on motor activity and negative affect or high on motor activity and positive affect. Greater right frontal EEG activation was found in 9-month olds who displayed high motor activity and negative affect in addition to inhibited behaviour at 14-months of age. No frontal EEG associations were found for the infants with high motor and positive affect. The results suggest that negative reactivity, inhibition and high motor activity are linked to greater right frontal EEG asymmetry as early as 9-months of age. Further research has also found links between infant negative affect, and frontal asymmetry patterns (Henderson et al., 2001). Henderson and colleagues (2001) examined the relationship between maternal reports of negative reactivity, social wariness and 9-month-old infant EEG frontal asymmetry patterns. Negative reactivity was predictive of social wariness for infants with greater right frontal EEG asymmetry but not for infants with greater left relative frontal EEG asymmetry. The results suggest that differences in frontal EEG asymmetry patterns, which are linked to infant temperament, contribute to differences in social behaviour. Frontal EEG asymmetries are also believed to be an indicator of temperament (LoBue et al., 2011). Infants who exhibit greater left frontal activity at rest are regarded as having easier temperaments, and are more easily soothed and calmed in comparison to infants who display greater right frontal activation (Fox, Henderson, Rubin, Calkins & Schmidt, 2001). For instance, a recent study by LoBue et al. (2011) investigated the link between prefrontal asymmetry and infant temperament. Parents initially completed a modified version of the Infant Behaviour Questionnaire (Gartstein & Rothbart, 2003) to provide information on infant temperament. Twenty three 7-to 9-month-old infants were presented with videos which were either accompanied by a happy or fearful voice whilst an

EEG recording was taking place. Results revealed that frontal asymmetry was associated with parents' reports of their infants temperament. An increase in left frontal brain activation was associated with higher parental ratings of approach behaviours such as soothability. The results suggest that frontal asymmetry patterns observed in infancy are associated with differences in infant temperament.

1.3.2.3. Approach/Withdrawn personalities

Research has moved towards interpreting positive and negative asymmetries in the PFC as approach and withdrawal behaviour patterns (Field & Diego, 2008), with negative affect being associated with withdrawal behaviours (such as fear and disgust) and happiness being associated with approach behaviours (Davidson et al, 1990). Approach and exploring behaviours are characterised by greater left frontal brain activation (Davidson et al, 1990; Field & Diego, 2008). Withdrawal and fleeing behaviours from the external environment are characterised by greater right frontal brain activation (Davidson et al, 1990; Field & Diego, 2008). For example, Coan & Allen (2003) examined the relationship between frontal EEG asymmetries and the Behavioral Inhibition (BIS) and Behavioral Activation Scales (BAS: Carver & White, 1994). Greater left frontal activation was positively correlated with the BAS. However, greater right activation was not associated with scores on the BIS. The authors believed this was due to the relationship between the BIS and right frontal activation being complex. Despite this finding, other studies have found that greater right frontal brain activation is coupled with increased behavioural response or more intense reactions to negative stimuli (Wheeler et al., 1993). Wheeler and colleagues (1993) conducted an EEG study to investigate frontal brain asymmetry and emotional reactivity. Baseline EEG was recorded from ninety female participants on two occasions, three weeks apart. After the second EEG recording participants were shown brief film clips which were designed to elicit either positive or negative emotions. Participants gave each film clip and emotional-rating after viewing. Greater left frontal activation was found for individuals who reported more intense positive affect in response to the positive films. Additionally, greater right frontal activation was displayed in individuals who reported more intense negative affect in response to the negative clips. The results suggest that positive and negative traits in individuals are reflected in frontal asymmetry patterns.

Associations between frontal EEG asymmetry profiles have been used for interpreting approach versus withdrawal behaviour patterns which indicate trait tendencies within individuals (Coan & Allen, 2003; Davidson et al, 1990) even in infancy (Hane, Fox, Henderson & Marshall, 2008). Hane and colleagues (2008) explored approach and withdrawal behaviours in 779 4-month-old infants in relation to EEG frontal asymmetries. Infants were measured on their levels of attention towards a puppet. The amount of positive and negative motor reactivity infants displayed was measured. Reulst revealed that infants who mostly disaplyed withdrawn behaviours towards the puppet had greater right frontal brain activation. Additionally, infants who were more engaged with the puppet and displayed more approach behaviours towards the stimulus had greater left frontal brain activation. Hane et al., (2008) believe that frontal asymmetries, even in infancy, are suggestive of whether an individual will display approach or withdrawn behaviours.

This section has demonstrated that frontal asymmetries can show individual differences in trait tendencies. Greater left frontal activation has been coupled with positive emotions in adults and infants (Dawson et al., 1992: Davidson et al., 1990; Fox & Davidson, 1987; Wheeler et al., 1993), calmer temperaments in infants (Fox et al., 2001; Gartstein & Rothbart, 2003; LoBue et al., 2011) in addition to approach behaviours in adults and infants (Coan & Allen, 2003; Davidson et al., 1990; Field & Diego, 2008; Hane et al., 2008; Wheeler et al., 2003). Furthermore, greater right frontal activation has been associated with negative emotions in adults and infants (Dawson et al., 1992: Davidson et al., 1990; Fox & Davidson, 1987; Wheeler et al., 1993), greater negative reactivity in infancy (Fox et al., 2001; Gartstein & Rothbart, 2003; LoBue et al., 2011) as well as withdrawn behaviours in both adults and infants (Coan & Allen, 2003; Davidson et al., 1990; Field & Diego, 2008; Hane et al., 2008; Wheeler et al., 2003).

1.4. Emotion based disorders

This next section will briefly introduce the literature on depression and anxiety in terms of frontal asymmetries and the hypothalamic-pituitary-adrenal (HPA) axis. As the content covered here is similar to the content of Chapter 4 Part 2 (The effect of mothers anxiety symptoms upon infant brain functioning at rest), Chapter 4 Part 2 will review in depth the role of both of these disorders upon adult and infant brain functioning, with a focus on frontal asymmetry patterns. The role of depression upon infant and maternal behaviours will be discussed in greater detail within the current chapter; however, the role played by anxiety will again be explored further in Chapter 4 Part 2.

1.4.1. Emotion based disorders and frontal asymmetries

Differences in frontal asymmetries are seen as a marker of risk for a variety of emotion based disorders, such as depression and anxiety (Fingelkurts, Fingelkurts, Rytsala, Suominen, Isometsa & Kahkonen, 2007). Differences in frontal EEG asymmetry have been found in people who suffer from anxiety and depression when compared with people who do not (Beaton, Schmidt, Ashbaugh, Santesso, Antony & McCabe, 2008; Henriques & Davidson, 1991). A meta-analytic study by Thibodeau Jorgensen, and Sangmoon (2006) confirmed that anxious and depressed symptomatology is strongly associated with right frontal brain activation. Greater right frontal brain activation has also been found in infants of depressed mothers (Dawson, Frey, Panagiotides, Osterling, & Hessi, 1997; Diego, Field, Jones & Hernandez-Reif, 2006; Field & Diego, 2008; Jones, Field, & Almeida, 2009) but to date has not been explored in infants of anxious mothers. Please refer to Chapter 4 Part 2 for a more in-depth review of the literature.

1.4.2. Emotion based disorders and the HPA axis

The hypothalamic-pituitary-adrenal (HPA) axis is a system which is involved in human stress responses (Tarullo & Gunnar, 2006). As described by Tarullo and Gunnar (2006), in response to a stressor, the hypothalamus increases the production of corticotropin releasing hormone (CRH) and arginine vasopressin (AVP). These hormones are released into the pituitary gland which results in the pituitary gland releasing andernocorticotropic hormone

(ACTH) which stimulates the adrenal gland to produce cortisol, a steroid hormone responsible for increasing blood sugar and supressing the immune system.

Overactivation of the HPA axis is commonly seen in emotion based disorders which can result in detrimental, toxic effects on the brain due to elevated cortisol levels (Brown, Varghese & McEwen, 2004; Chaudieu, Beluche, Norton, Boulenger, Ritchie & Ancelin, 2008; Mantella, Butters, Amico, Mazumdar, Rollman, Begley et al., 2008; McEwen, 1998).Within depression, elevated cortisol levels are a well-replicated finding within the literature (Brown, Varghese & McEwen, 2004). Depressed individuals are suggested to have a dysregulated HPA axis response during stressful situations. For instance, Young, Lopez, Murphy-Weinberg, Watson and Akil (2000) exposed depressed and non-depressed participants to a social stressor and recorded cortisol levels in both groups. Depressed participants displayed higher baseline cortisol levels and further elevated levels in response to the social stressor. The authors believe this finding demonstrates an absence of cortisol inhibition mechanisms in depressed individuals. Similarly, elevated cortisol levels have also been found for individuals with anxiety disorders (Chaudieu et al., 2008; Mantella et al., 2008).

The HPA axis is not fully developed at birth, with developmental changes and childhood experiences impacting HPA axis function, most notably cortisol levels (Gunnar & Donzella, 2001). During infancy and childhood, the development of the HPA axis is shaped by social experiences, with development being vulnerable to psychological stressors such as the absence of sensitive and responsive caregiving (Tarullo & Gunnar, 2006). Depressed and anxious mothers have been found to be unresponsive and withdrawn towards their infants, exhibiting reduced maternal sensitive responsivity (Diego et al., 2006; Feldman et al., 1997;

Jones et al., 2001). Research has demonstrated that maternal depression (both prenatal and postnatal) is associated with higher cortisol levels in infants, children and adolescents (Ashman, Dawson, Panagiotides, Yamada & Wilkinson, 2002; Brennan, Pargas, Walker, Green, Newport & Stowe, 2008; Diego, Field, Hernandez-Reif, Cullen, Schanbery & Kuhn, 2004; Essex, Klein, Cho & Kalin, 2002; Halligan, Herbert, Goodyer & Murray, 2004; Lundy, Jones, Field, Nearing, Davalos, Pietro, et al., 1999). For instance, Lundy et al., (1999) initially measured cortisol levels in depressed pregnant mothers and later obtained cortisol measurements for their newborn infants. The authors found that depressed women with increased cortisol levels also had newborn infants with elevated levels. The results suggest that maternal prenatal cortisol levels could be a potential mechanism of transmitting psychopathology from mother to child. Interestingly, the literature has also suggested that the duration of maternal depressive symptoms may influence the extent to which infant physiology is affected (Diego et al., 2004). Diego et al., (2004) explored the effects of prepartum, postpartum and chronic depression on newborn infants. For the mothers, mood and biochemical measures were taken during pregnancy and infant EEG and biochemical measures were taken shortly after birth. Infants of mothers with prepartum and postpartum depression displayed higher levels of cortisol in addition to greater relative right frontal EEG asymmetry. Interestingly, infants of mothers who displayed prepartum depressive symptoms showed greater right frontal EEG asymmetries in comparison to the other groups. The results suggest that the physiological effects of maternal depression may depend more on the duration of depressive symptoms.

Within the literature it is also acknowledged that maternal anxiety is also related to infant HPA axis function (Brennan et al., 2008). Increased cortisol levels have also been found for infants of anxious mothers (Gutteling, de Weerth & Buitelaar, 2005; O'Connor, Ben-Shlomo, Heron, Golding, Adams & Glover, 2005; Warren, Gunnar, Kagan, Anders, Simmens, Rones et al., 2003). Warren et al., (2003) conducted a study exploring infant temperament, neurophysiology and maternal panic disorder. Maternal panic disorder was associated with increased cortisol levels in infants which the authors interpreted as an early indicator of risk for anxiety. It is important to note however, that given the comorbidity of anxiety and depression, the relationship between these two disorders and HPA axis function currently remains unclear (Brennan et al., 2008).

1.4.3. Depression

The DSM-5 (American Psychiatric Association, 2013) states that when an individual suffers from depression they experience a depressed mood or loss of interest or pleasure. Depressed mood is said to last for most of the day and the individual will have decreased interest or pleasure in all or most activities. The individual may also experience significant weight loss or weight gain, insomnia or hypersomnia, fatigue, feelings of worthlessness, and inappropriate guilt. Other symptoms of depression include diminished ability to concentrate on tasks and in some cases recurrent thoughts of death. Depression affects approximately 25% of women and 12% of men (Gelenberg, 2010) and is increasingly common in women of childbearing age (Bernard-Bonnin, 2004). Due to the nature of the disorder, even after an individual has recovered, the risks of experiencing depression again increase over time (Gelenberg, 2010).

1.4.3.1. Differences in maternal behaviour

There is a general agreement that two interaction styles exist within depressed mothers (Field, Diego, Hernandez-Reif, Shanberg & Kuhn, 2003). These interaction styles have typically been categorised as either withdrawn or intrusive (Diego et al., 2006; Jones, Field, Hart, Lundy & Davalos, 2001). Some depressed mothers show withdrawn behaviours with their infants compared to other who display intrusive behaviours towards their infants (Cohn, Campbell, Matias, & Hopkins 1990; Field, Healy, Goldstein, & Guthertz,1990). Mothers with a withdrawn interaction style are found to show disengaged behaviour, lack of touching and vocalisation with their infant, as well as having a general flat affect. In contrast mothers with an intrusive interaction style show quite rough physical contact and fast, loud vocalisation with their infant (Diego et al., 2006). Pelaez-Nogueras, Field, Hossain and Pickens (1996) explored depressed and non-depressed mothers interactions with their 3-month-old infants. Depressed mothers were filmed interacting with their own child and with a non-depressed infant. The non-depressed mothers were filmed in the same scenarios. The authors found that depressed mothers used significantly less facial expressions, physical activity, game playing and infant related behaviour in comparison to their non-depressed counterparts. These differences were consistent even when depressed mothers were interacting with the infants of non-depressed mothers. Pelaez-Nogueras and colleagues (1996) believe that these results demonstrate that depressed mothers show less optimal behaviours towards infants in general. Differences in mother-infant interactions in depression have been widely acknowledged throughout the literature (Cohn, Campbell, Matias, & Hopkins 1990; Field et al., 1990; Diego et al., 2006).

1.4.3.2. Differences in infant behaviour

Maternal depression affects infant behaviour (Diego et al., 2006) and is considered a risk factor for the socio-emotional and cognitive development of the child (Bernard-Bonnin, 2004). Field (2010) outlined the affect depression can have on an infant's behaviour. For instance infants of depressed mothers have been shown to display less interaction play behaviours such as smiling, vocalisations, smiling and imitation. A recent review by Field, Diego and Hernandez-Reif (2009) also revealed that infants of depressed mothers are less responsive to faces and voices, which the authors attributed to higher arousal, less attentiveness, and less empathy. A study by Moszkowski, Stack, Girouard, Field, Hernandez-Reif and Diego (2009) revealed differences in infants of depressed mothers touching behaviours. Touching behaviour was recorded during a period of maternal separation and maternal unavailability which involved the mother sitting in front of her infant but adopting a still-face. Infants of depressed mothers were found to use significantly more reactive types of touch such as patting, grabbing, and pulling, indicating greater levels of activity in these infants. It has been hypothesised that infants of depressed mothers show differences in behaviour as they are matching their mother's behaviour and level of responsiveness (Tronick & Cohn, 1989).

In summary, maternal depression is a common disorder among women of child-bearing age (Bernard-Bonnin, 2004). Individuals with depression have been found to display greater right frontal brain activation which is coupled with withdrawn behaviours (Thibodeau et al., 2006). Interestingly, greater right frontal brain activation has also been found in infants of depressed mothers (Dawson, Frey, Panagiotides, Osterling, & Hessi, 1997; Diego, Field, Jones & Hernandez-Reif, 2006; Field & Diego, 2008; Jones, Field, & Almeida, 2009). Furthermore, differences in mother-infant interactions have been widely acknowledged throughout the literature (Cohn, Campbell, Matias, & Hopkins 1990; Field et al., 1990; Diego et al., 2006), with depressed mothers typically showing less optimal behaviours towards their infant (Pelaez-Nogueras et al., 1996) and their infants displaying less interaction play behaviours (Field, 2010). The research therefore suggests that the differences found in frontal EEG asymmetries are linked to the behavioural differences in depressed mother-infant interaction.

1.5. Chapter outline

Now that the relevant background literature has been reviewed, Chapter 2 (General Methodology) will move on to explain the methods used within this thesis, focusing mainly on the administration of Electroencephalography (EEG) and methods of data analysis. Chapter 3 (Speech and Non-Speech Processing in Infants) will explore the role of social and non-social stimuli in infants in the auditory domain. Chapter 4 Part 1 (Social and Non-Social Processing in Infancy) will investigate visual social and non-social stimuli upon infants frontal asymmetries at rest. Chapter 4 Part 2 (The Effect of Mothers Anxiety Symptoms upon Infant Brain Functioning at Rest) will move onto researching the role of anxiety upon infant frontal asymmetry patterns whilst taking the impact of social and non-social stimuli into account. Chapter 6 (Meta-Analysis: Depression and the Still-Face Paradigm) will explore the effect of a mother’s depression upon infant behaviour. Chapter 6 (General Discussion) will summarise and discuss the findings and impact of each of the chapters of this thesis.

CHAPTER 2

GENERAL METHODOLOGY

2.1. Introduction to the general method chapter

The chapter will outline participant recruitment for chapters 3 (Speech and Non-Speech Processing in Infants), 4 (Social and Non-Social Processing in Infancy), and 5 (The Effect of Mothers Anxiety Symptoms upon Infant Brain Functioning at Rest). It will also outline electroencephalography (EEG) as a neuroimaging technique and will focus mainly on the methodology in chapters 4 and 5 as the procedures used were the same. The specific EEG methodology used in chapter 3 will be discussed within the relevant chapter. Similarly, the meta-analysis methods used in chapter 6 (Meta-Analysis: Depression and the Still-Face Paradigm) will also be explained within the appropriate chapter.

2.2. Participant Recruitment

Participants for chapters 3, 4, and 5 were recruited via the Infant and Child Laboratory at The University of Birmingham. Additionally, participants for chapter 5 were also sought from The Barberry, National Institute of Mental Health.

2.2.1. Recruitment for the chapters 3, 4 and 5

Ethical approval was obtained from The University of Birmingham. Infants for the control group were recruited via The University of Birmingham’s Infant and Child

Laboratory. Mothers were approached at different infant, toddler, and child play groups and other events. Their contact details and the child's date of birth were recorded and entered into a secure, password protected database. If infants were 3-to 5-months old or approaching 3-months old, their mothers were contacted by the author and given more information about the studies. If the mothers were interested in taking part, an appointment was made for them to come in to the laboratory to participate. Prior to participation, mothers were given a consent form to sign and were given the opportunity to ask questions. The consent form included details of confidentiality and anonymity of the data and participant identity. Additionally, the mothers were informed of their right to withdraw from the study at any point.

2.2.2. Recruitment for chapter 5

NHS ethical approval for the current study was sought and obtained from the Birmingham East, North and Solihull Research Ethics Committee (REC number: 10/H1206/73). Participants from The Barberry were approached if they had a formal clinical diagnosis of Major Depressive Disorder or an Anxiety Disorder from a clinician and were deemed well enough to participate. Potential participants were informed about the study by Dr. Mary McGuinness (a clinical psychologist at the hospital) after group or individual therapy. At the next group or individual therapy session potential participants were approached and were given a small presentation about the study. Information sheets and leaflets which had previously been approved by the NHS were also given to the potential participants. If a mother was interested in participating at this point, a visit was arranged for the next group or individual session. This gave the experimenter the opportunity to obtain informed signed consent in addition to arranging an appointment for the testing to take place. Only three mothers with a clinical diagnosis of anxiety were recruited. These mothers were not included in the analysis in chapter 5 as they were all on medical treatment during their pregnancy which was deemed as a confounding factor.

2.2.3. Inclusion and exclusion participant criteria

Infants were able to participate in the current studies if they were aged between 3- and 5- months of age. Additionally, only data from typically developing infants was included in the final analyses, the unknown effects of medical disorders upon infant brain functioning was deemed as a potential confound within the current studies. Further consideration for inclusion and exclusion criteria was given to the mothers. Infants were able to participate if their mothers did not have an existing mental disorder of if their mothers did have a current diagnosis of depression or an anxiety disorder. Infants were not able to participate if their mothers had a diagnosis or pre-existing diagnosis of other disorders such as bi-polar disorder or schizophrenia. The effects of these disorders (and others) upon mother and infant brain functioning is not known and the current studies were only interested in exploring typical infant brain functioning and brain functioning of infants with depressed and/or anxious mothers. Furthermore, recent evidence has shown that foetal exposure to medications such as SSRIs, which are commonly used for the treatment of depression, can have adverse effects on infant brain functioning (Laine, Heikkinen, Ekblad, Kero, 2003). Therefore, participants were excluded from the final analyses if their mother had been on medication during pregnancy, as this could be a potential confound on the study results.

2.3. EEG

Neuroimaging tools are widely used in the measurement of neurodevelopment (Nelson & McCleery, 2008). Investigating neurodevelopment allows researchers to learn about brain development, and how individuals' brains respond to certain stimuli. This aids understanding of how we use our brain. For example, how we learn, how we process language and faces, and how our memory functions. EEG is a neuroimaging tool which measures electrical activity, naturally produced by the brain (Nelson & McCleery, 2008).

2.3.1. Advantages of EEG

The advantages of EEG include the ability to measure the time course of processes in the brain in response to stimuli and fast application, making EEG suitable for infants and children (Nelson & McCleery, 2008). EEG has been used to investigate a variety of areas such as emotion processing (Davidson et al., 1990; Dawson, et al., 1992), language processing (Elk, Schie, Zwann & Bekkering, 2010) and brain functioning within different disorders for example, depression and anxiety (Beaton, et al., 2008; Henriques & Davidson, 1991). Furthermore, EEG is relatively inexpensive in comparison to other imagining techniques such as fMRI and MEG, additionally it also allows for participant movement during testing (Nelson & McCleery, 2008). EEG was therefore deemed the most appropriate method to explore the effect of social and non-social stimuli (chapters 3 & 4) and maternal anxiety (chapter 5) upon infants brain functioning.

2.3.2. Limitations of EEG

Despite the usefulness and appropriateness of EEG for the purpose of this thesis, it is important to note that this methodology does present some limitations. Firstly, EEG measurements obtained only reflect the surface measurements of activity, which is a result of activity from many different sources in the brain (Kushnerenko et al., 2002). This means that although the EEG measurement can tell us where activation is seen on the scalp, this scalp location can give a misleading impression as to the location of the source of the activity and in fact tells us very little about the area of the brain which actually generated the activation. Therefore, it is possible that activation seen in the frontal lobes may be a direct result of activation in another area, for example a rebound of activation in the temporal lobes (Kushnerenko et al., 2002). As a result, conclusions about the source of brain activation should not be drawn from the current thesis.

An additional weakness of EEG methodologies is referred to as the inverse problem. The inverse problem refers to the ability to accurately measure brain activation from a limited number of electrodes placed on the scalp (Tian & Li, 2011). For instance, in the current thesis, the EEG system used relied upon 128 electrodes to record brain activation across the scalp. However, if each neuron is treated as a potential source of neural activity, then the number of sources of electrical activation across the scalp is far greater than the number of electrodes used to measure this activity (Tian & Li, 2011). As a result, the number of electrodes is regarded as insufficient in providing a precise measurement of neural activation (Grave de Peralta Menendez and Gonzalez Andino, 1998). Although this is a common limitation for EEG methodologies, there is not currently a unique solution to the inverse problem (Baillet, Mosher & Leahy, 2001). Therefore, the current thesis needs to be mindful of this issue when drawing conclusions about regions of neural activation in relation to the stimuli presented.

Thirdly, attrition rates in infant EEG studies can be high which can reduce statistical power (Stets, Stahl & Reid, 2012). Reasons for high attrition rates include; frequent eye, head and body movements, the infant not being accustomed to the EEG net and lack of attention to stimuli due to long trials (DeBoer, Scott & Nelson, 2007; Stets, Stahl & Reid, 2012). With this in mind, the current thesis aimed to have a larger sample to allow for high attrition rates. Furthermore, special care was taken during the studies to minimise infant movement and increase attention for example, pause screens were inserted after each thirty second presentation of the social and non-social study (Chapter 4), this was done to maximise successful completion of each trial. Additionally, toys and researchers were used to distract the infants during the EEG net application. As a further precaution, testing timeslots were arranged for when parents deemed their infants to most likely be at their happiest. Infants of anxious mothers were not deemed to be at a higher rate for attrition, as previous research did not find a link between infant attrition rates and maternal anxiety (Davidson & Fox, 1989).

2.3.3. Event Related Potentials

One method of measuring neurodevelopment is through the use of event-related brain potentials (Nelson & McCleery, 2008). Event-related brain potentials (ERP) reflect changes in the brain's electrical activity when an individual is presented with a stimulus or event (Nelson & McCleery, 2008), they provide a non-invasive way of measuring brain activity during cognitive processing. ERP's can be reliably measured using electroencephalography EEG. This method will be used in chapter 3 to explore the role of speech processing in infants and will be discussed within the relevant chapter.

2.4. Chapters 4 and 5 methodology

Chapters 4 and 5 relied upon the measurement of Power Spectral Density (PSD) as opposed to ERP as used in Chapter 3. PSD refers to the measurement of the amplitude and consistency of synchronous firing of large numbers of neurons at rest. Chapters 4 and 5 measured Power Spectral Density (PSD) in the frontal regions of infants brains in response to certain stimuli. Due these chapters sharing a common method for obtaining resting EEG, this method and the offline data processing procedures will be outlined here.

2.4.1. Stimuli

The stimuli for this study were custom made (720 x 576 pixels) thirty second videos which were either non-social (computerised objects bouncing around the screen associated with contingent sounds) or social (women and men reading nursery rhymes). Non-social videos were created from video screen recordings of screensavers from Windows (XP, 2001) using the software Snagit (version 10.0.0, 2010). Sounds to accompany the videos were created and normalised in Audacity (version 1.3.12, 2010) to ensure maximum and minimum amplitude did not differ for each sound track. Windows Movie Maker (version 2.6, 2010) was employed to combine the screen recordings and the sound tracks. Additionally, brightness was adjusted to 50% for each created video. Recordings of individuals speaking nursery rhymes were imported into Windows Movie Maker (version 2.6, 2010) where they were cropped into thirty second epochs. The sound track for each video was exported to Audacity (version 1.3.12, 2010). Each sound track was then normalised using the same criteria which had been applied to the non-social videos. The sound tracks for the social videos were exported back to Windows Movie Maker (version 2.6, 2010) to be combined with the video recordings. Brightness levels were adjusted to 50% for the social videos as they were with the non-social videos. Twelve thirty second videos were created for each condition. The created stimuli were presented on a computer screen with accompanying sounds coming from speakers positioned in front of the mother and infant, at a maximum sound level of 65 dB measured from the infant's head.

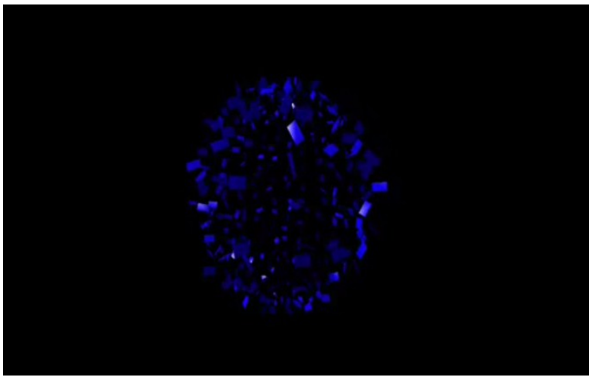

Figure 2.1. Non-Social condition

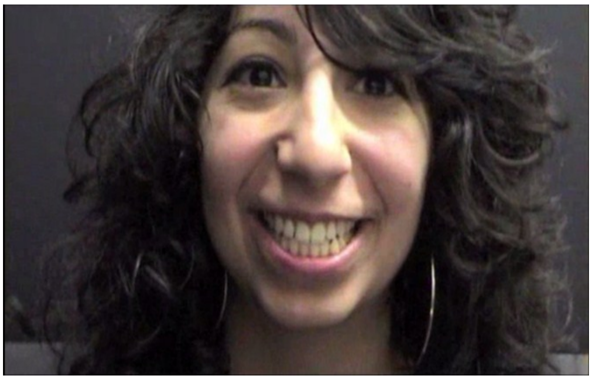

Figure 2.2. Social condition

At this point, it is important to note that the created stimuli presented potential methodological limitations. The social stimuli were highly unique in comparison to the non-social stimuli as they contained human movement and voices. This made the social stimuli virtually impossible to match to the non-social stimuli. Instead, the non-social stimuli created were at best a comparison baseline condition. The social condition was positive and engaging for infants in comparison to a neutral non-social condition. This therefore left open the possibility that the positive, engaging nature of the social stimuli could influence infant brain functioning as opposed to the social nature of the condition itself driving infant brain functioning.

2.4.2. Procedure

Infants were seated on their mother's lap facing the computer screen and speakers, at a distance of one metre (with the distance measured from the infant's head). Once the EEG net had been placed on the infant and EEG recording had commenced, video stimuli were presented to infants for the social and non-social conditions. The non-social stimuli consisted of twelve different videos of computerised objects moving around the screen with accompanying sounds. The social stimuli also consisted of twelve videos but of men and women reading nursery rhymes in an enthusiastic, child-directed manner. Each video segment was presented for thirty seconds with pauses in between to ensure stimuli were only presented when the infant was watching. Two videos of the same condition were presented consecutively (i.e., social video: pause: social video or non-social video: pause: non-social video). The order of the stimuli was counterbalanced, meaning infants either started watching the social or non-social videos first, with the order of videos within each condition being presented randomly. A total of six minutes of videos for each condition were available for each infant to watch, the number of videos viewed by the infant depended on how willing the child was to continue. Regular breaks were taken in between videos to ensure infants were entertained and content.

2.4.3. EEG Recording

The EEG was recorded continuously using a 128-channel Hydrocel Geodesic Sensor Net (HCGSN, Electrical Geodesics, Ins., Eugene, Oregon), referenced to a single vertex electrode, Cz (sample rate = 500 Hz; online highpass filter = 0.1 Hz) (Tucker, 1993). The HCGSN allowed for a non-invasive recording of brain electrical activity through a net which was comfortable and fast to apply. The net was soaked in an electrolyte solution for 3- to 5-minutes before being applied to the infants head, allowing for ease of application. Gains and zeros were measured by the system for each participant prior to net application. Electrode impedance was kept below 100k, as recommended by the manufacturer.

EEG recordings were processed offline by the researcher and a research assistant using Netstation 4.5.1. software (EGI, Eugene, Oregon). The research assistant received extensive training in EEG analysis in terms of learning the procedure and how to identify artefacts within the collected data. Due to the nature of analysing continuous EEG data, there is no experimental reason to believe that biases in the editing process might have affected the results.

The procedures for processing the data in addition to the settings were recommended by the manufacturer (EGI, Eugene, Oregon). The data were filtered (highpass filter = 0.1 Hz, 50Hz Notch), segmented and then additionally clinically segmented. Bad electrode channels within the data were selected and replaced. A by hand artifact detection was conducted on the segmented data to identify portions containing artefacts, including eye blinks and infant movement. The remaining, artefact free, data segments were selected and saved for each participant per condition (social and non-social). A combining tool in Netstation was used to combine all the separate saved files for each condition and infant.

2.4.4. Data Analysis

EEG data were exported in RAW format for use in a purpose built MATLAB-based program for data analysis. The purpose built MATLAB program was based on one created by Grieve, Isler, Izraelit, Peterson, Fifier, Myers and Stark (2008), as the authors found that this program produced statistically-reliable measurements of PSD. In accordance with Grieve et al.’s (2008) methodology, the current study’s MATLAB program split the EEG data into one second epochs. Fast Fourier Transforms (FFTs) were calculated for each epoch using a 500ms window with 60% overlap. Average PSD values were outputted and log transformed in the infant alpha band (6-9 Hz) for each electrode group, in preparation for statistical analysis.

2.4.4.1. Frontal EEG asymmetry calculation

EEG asymmetries show the difference in power between the right and left hemispheres (Field & Diego 2008). Field and Diego (2008) explain that asymmetries are calculated by subtracting the power of a right hemisphere electrode site from the same electrode site on the left hemisphere. Therefore if a positive value is displayed this indicates greater right than left EEG power, whereas, if a negative value is displayed then this indicates greater left than right EEG power (Field & Diego 2008). At this point it is important to note that an inverse relationship exists between EEG PSD power and brain activity (Lindsley & Wicke, 1974 cited in Gable & Harmon-Jones, 2008; Schmidt & Trainor, 2001; Singer & Zeskind, 2001). Specifically, greater EEG power is associated with decreased brain activity and lower EEG power is associated with increased brain activity. This is due to the fact that if an area of the brain is not involved in a certain process, neurons in this area will become entrained in a resting alpha rhythm of firing which results in increased EEG power, which in turn shows decreased brain activity (which is characterised by encoding and other activities that are not in locked synchrony with the resting rhythm) (Lindsley & Wicke, 1974 cited in Gable & Harmon-Jones, 2008; Schmidt & Trainor, 2001; Singer & Zeskind, 2001).

2.5. Statistical analysis

The analyses conducted will be explained and discussed within the relevant chapters as each chapter differs in their analysis procedures.

CHAPTER 3

SPEECH AND NON-SPEECH PROCESSING IN INFANTS

3.1. ABSTRACT

Exploration of speech processing in infancy is necessary to provide a deeper insight into the development of mechanisms in the brain as currently little is known about the neural mechanisms which underlie speech processing in infancy (Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002; Vouloumanos & Werker, 2007). The present study was designed to examine the time-course and neural mechanisms involved in the processing of speech versus non-speech stimulus categories in infancy. Twelve three-to-five month old infants participated in a match/mismatch event-related potential (ERP) study where several pairs of stimuli were deployed from the same category (e.g., Speech /ba/ followed by Speech /da/) or from different categories (e.g., Speech /ba/ followed by Non-Speech analogue of /da/). As this procedure was employed for both speech and non-speech stimuli, it allowed for the examination of match and mismatch mechanisms for speech versus non-speech processing. The results of the current study suggest specialisation of the left hemisphere during speech processing as a mismatch effect was found in the frontal central regions and the temporal regions in infancy. Additionally, as early and late going components were found in the left-frontal-central region, this appears to reflect an early perceptual role followed by a later higher level cognitive role of speech processing during the speech mismatch condition in this region. A late going component was identified in the left-temporal region which suggests the cognitive evaluation of stimuli during the speech mismatch condition. Despite the close nature of the speech and non-speech stimuli, infant brain responses in the speech mismatch conditions strongly suggest that infants are able to discriminate between the categories. The findings of the current study suggest sophisticated neural network for speech processing exists from early infancy.

3.2. INTRODUCTION

Speech is a linguistic signal from a human source which allows for communication through the use of specific sounds and precise articulatory gestures (Schultz & Vouloumanos, 2010). Infants show enhanced language processing in their first year in terms of increased attention to speech and their ability to discriminate between different types of speech (Schultz & Vouloumanos, 2010). Enhanced language processing has been suggested to aid the development of social and attention related functions early in life. For example, infants are able to discriminate between different types of speech (infant-directed and adult-directed) and are able to attend to a particular one in order to hear it more regularly (Cooper & Aslin, 1990). Even before word production, infants are able to recognise familiar words (Halle & De Boysson-Bardies, 1996; Harris, Yeeles, Chasin & Oakley, 1995), different languages (Bosch & Sebastián-Gallés, 1997; Nazzi, Floccia & Bertoncini, 1998; Nazzi, Jusczyk & Johnson, 2000), and even distinguish differences between the more complex parts of speech such as consonants (Halle & De Boysson-Bardies, 1996) and point vowels (Polka & Bohn, 2003). Research on the specific mechanisms of speech processing in infancy is limited (Dehaene-Lambertz Dehaene, & Hertz-Pannier, 2002; Vouloumanos & Werker, 2007). However, infants have been shown to have an early speech bias, for instance, they will attend to speech over non-speech for longer periods of time and will also show a preference for listening to speech over non-speech when the opportunity is presented (Shultz & Vouloumanos, 2010; Vouloumanos & Werker, 2004; Vouloumanos & Werker, 2007).

Research has demonstrated a bias in infant attention when infants are presented with speech and non-speech stimuli. For instance, infants have been found to attend longer to speech stimuli as opposed to non-speech stimuli such as synthetic speech, warbled tones and white noise (Colombo & Bundy, 1981; Samples & Franklin, 1978; Spence & DeCasper, 1987). Further to this, infants have different behavioural responses to speech and non-speech stimuli, showing a preference for speech (Shultz & Vouloumanos, 2010; Vouloumanos & Werker, 2004; Vouloumanos & Werker, 2007). Vouloumanos and Werker (2004) exposed 2- to 7-month old infants to nonsense speech and complex non-speech analogues in order to explore infant behavioural responses. The authors found that infants from 2-months of age attended longer to speech sounds. Furthermore, Vouloumanos and Werker (2007) replicated this finding in 1- to 4-day old newborn infants. The infants were presented with speech and non-speech stimuli each time their sucking amplitude on a pacifier increased above an 80% pre-recorded baseline. Interestingly, the infants significantly increased their sucking amplitude on the pacifier for the speech stimuli as opposed to the non-speech stimuli. The authors believe this finding provides support for the viewpoint that the detection of language is innate, as even neonates were able to distinguish between speech and non-speech despite their very limited experience with language.

Presently, little is known about the neural mechanisms which underlie speech processing in infancy (Dehaene-Lambertz et al., 2002; Vouloumanos & Werker, 2007). Research however, has demonstrated that infants recruit different neural resources for speech and non-speech processing (Dehaene-Lambertz et al., 2002; Peña, Maki, Kovacic, Dehaene-Lambertz, Koizumi, Bouquet, et al., 2003). In adults, early research by Broca (1861; as cited in Neil, 2006) and Wernicke (1874; as cited in Neil, 2006) provided evidence of the value of the left temporal and left frontal cortices in language processing. Frontal activations are suggested to be associated with task demands and temporal activations with lexical processes

(Friederici, 2006). Furthermore, recent neuroimaging studies have provided supporting evidence, demonstrating the importance of these regions in speech and language processing in adults (Dronkers, Wilkins, Van Valin, Redfern & Jaeger, 2004; Hickok & Poeppel, 2007; Keller, Crow, Foundas, Amunts & Roberts, 2009; Price, 2010). Interestingly, similarities have been found between the areas recruited for speech in the infant brain and those used for speech processing in the adult brain (Dehaene-Lambertz et al., 2002; Pang, Edmonds, Desjardins, Khan, Trainor & Taylor, 1998).

Studies investigating speech processing in infants have relied upon different methods including fMRI (Dehaene-Lambertz et al., 2002; Dehaene-Lambertz, Hertz-Pannier, Dubois, Me'Riaux, Roche, Sigman, et al., 2006), fNIRS (Kotilahti, Nissila, Nasi, Lipiainen, Noponen, Merilainen, et al., 2010; Minagawa-Kawai, Van der Lely, Ramus, Sato, Mazuka & Dupoux, 2010) and EEG (Dehaene-Lambertz, 2000; Dehaene-Lambertz & Baillet, 1998; Pang et al., 1998). Despite studies reporting similarities between the areas recruited for speech processing in the adult and infant brain (Dehaene-Lambertz et al., 2002; Pang, et al., 1998), the findings in infancy research are however still extremely mixed. For instance, in an fMRI study Dehaene-Lambertz et al. (2002) explored brain activation in 3-month-old infants while they were exposed to normal and reversed speech. Left-lateralised brain regions including the superior temporal and angular gyri were activated during normal speech exposure. Additionally, the right prefrontal cortex was also activated in awake infants in response to normal speech. Dehaene-Lambertz et al. (2006) in a later fMRI study presented 3-month-olds with sentences in their native language and did not find left lateralisation of speech. This study revealed bilateral activation in the temporal regions in addition to greater right frontal activation in response to the speech stimuli. Initial brain activation for speech was also found in Heschl's Gyrus, an anterior part of the temporal regions. Both of these studies, however, do not provide specific information on areas specialised for speech as a non-speech control condition was not included. Further studies using fNIRS have included non-speech control conditions (Kotilahti et al., 2010; Minagawa-Kawai et al., 2010). For instance, Kotilahti and colleagues (2010) measured newborn infants brain responses to speech and music stimuli to investigate the lateralisation effects of speech. Results did not reveal a lateralisation effect for speech stimuli, as both hemispheres were activated by speech. However, a significant response was found for speech in the left hemisphere. The authors believe this result demonstrates that speech lateralisation has not yet fully developed in newborns but represents the beginning of specialisation of speech processing. Minagawa-Kawai and colleagues (2010) explored speech lateralisation in 4-month-olds and found different results. Infants were presented with speech (words from their native language and words from a non-native language) and non-speech stimuli (emotional voices, monkey calls and scrambled sounds). Brain blood flow responses were measured again using fNIRS but only in the temporal regions. Results revealed a clear left lateralisation to both native and non-native language speech stimuli in comparison to non-speech, with stronger lateralisation effects seen for the infants native language. Minagawa-Kawai et al. (2010) suggested that these results provide evidence for the left temporal region playing a language-specific role in infancy.

Further studies using electroencephalography (EEG) have used mismatch negativity (MMN) designs to explore speech and non-speech processing in infancy. The MMN is an electrophysical event-related potentials component which is generated when a mismatch in stimulus type occurs (Dehaene-Lambertz & Baillet, 1998). MMN designs use an oddball paradigm, as they reflect the brain's ability to discriminate sensory and perceptual differences between stimuli. Specifically, detecting a novel stimulus within a train of the same stimuli (Pang et al. 1998). Studies using the MMN methodology for exploring speech processing in infancy have also found differing results. Pang et al. (1998) explored speech processing in infants using the MMN design, whereby 8-month-old infants were presented with a train of syllables to explore the oddball detection effect. The results did not reveal a significant lateralisation effect for speech syllables. However, the C3 (left-central region) and the T3 (left-temporal region) did show significant MMN effects. The authors interpreted this result as infants demonstrating a left hemisphere specialisation for speech, with the C3 and T3 regions underlying speech processing from infancy. Furthermore, Dehaene-Lambertz and Baillet (1998) also explored speech processing in infancy with the use of the MMN method which employed different syllables which changed in tone. As in Pang at al.'s (1998) study, no lateralisation effects were found for speech. Significant MMN effects were seen across the temporal lobe. From this result, Dehaene-Lambertz and Baillet (1998) suggest that the temporal lobe is part of a dedicated neuronal network for processing speech and is apparent from infancy. Dehaene-Lambertz (2000) also used the MMN with syllables in differing tones to explore speech processing in 4-month-olds. Lateralisation was seen for speech, with higher voltages recorded over the left hemisphere. No differences in voltage were found between speech stimuli for differences in tone or type of syllable. Once again, a bilateral MMN effect was observed for the temporal lobes. The author explained this result as the temporal lobe having a main role in the perception and representation of different features of auditory stimuli.

Despite inconsistencies within infancy research, the literature suggests that the neural basis of language in a child's brain is similar to that of adults (Friederici, 2006). Researchers believe that the brain regions which are activated for language in adulthood are recruited in childhood (Friederici, 2006). The neural basis of typical language development is currently not fully understood within the literature (Friederici, 2006). However, research has suggested that left-lateralisation of language occurs around 5 years of age (Balsamo, Xu & Gaillard, 2006). Ahmad, Balsamo, Sachs, Xu and Gaillard (2003) found that 6-year-old children displayed activation in the left superior temporal gyrus and sulcus in addition to the left middle temporal gyrus when listening to stories. However, an fMRI study exploring activation in 6- to 10-year olds when listening to short text excerpt did not reveal left lateralisation but bilateral activation in the temporal, frontal and parietal regions (Ulualp, Biswal, Yetkin & Kidder, 1998). Despite differences within the literature, activations in the left middle temporal and right inferior frontal gyrus in response to language are correlated with age and semantic structure, with stronger lateralisation found in these regions for older children (Chou, Booth, Burman, Bitan, Bigio, Lu & Cone, 2006). This suggests that neuronal activation is correlated with an individual's understanding and experience of language. Therefore, it is possible that mixed findings within the infancy literature are a reflection of infants' limited understanding and experience with language.

Furthermore, mixed findings within the literature could be a result of the different neurological methods employed in these studies. Despite the differences presented in each method, it is important to note that mixed findings within the literature have also been found between studies using the same neurological methods. For instance, one fMRI study found left-lateralisation for infants in response to speech (Dehaene-Lambertz et al., 2002) in comparison to another which did not find a left lateralisation but a bilateral activation of the temporal regions (Dehaene-Lambertz et al., 2006). Further, similar findings have also been found between studies using different neurological tools. For example, EEG, fMRI and fNIR studies have found left lateralised brain regions when infants listen to normal speech (Dehaene-Lambertz, 2000; Dehaene-Lambertz et al., 2002; Minagawa-Kawai, Van der Lely, Ramus, Sato, Mazuka, & Dupoux, 2010). Therefore, mixed findings within the literature cannot be completely attributed to differences in neurological methods employed in each study (see Chapter 1, Section 1.1.8. for further information).

Exploration of speech processing in infancy is necessary in order to provide a deeper insight and understanding into the development of specialist mechanisms of social (speech) and non-social (non-speech) processing in the brain. A more complete understanding of the neural mechanisms of speech versus non-speech category discrimination is critical for our understanding of speech/language processing and communication. The literature within this area is limited (Dehaene-Lambertz, et al., 2002; Vouloumanos & Werker, 2007), with the majority of ERP studies exploring speech processing relying upon a single speech condition, without a non-speech comparison or a within-category discrimination of speech, i.e. comparing speech with reversed speech (Dehaene-Lambertz, 2000; Dehaene-Lambertz & Baillet, 1998; Pang et al., 1998). These designs also often heavily rely upon "oddball" brain responses to notably different stimuli for example speech stimuli changing in tone. The advantage of these MMN paradigms is that they indicate changes in brain responses to auditory changes regardless of where the listener’s attention is directed (Sussman, Chen & Fort, 2013). However, this design also leaves open the possibility that the brain response seen in the oddball trials is actually more representation of an attentional orienting brain mechanism as opposed to differences in language processing. For instance, within ERP studies, the P3 component is associated with involuntary orientation to an unexpected event

(Sussman, Chen & Fort, 2013). Furthermore, research has shown that MMN early going negative components overlap with the Nc (attentional component) in the temporal regions (Moreau, Jolicoeur, Lidji & Peretz, 2013), meaning that early perceptual processing and attentional component amplitudes may be masked by MMN components and vice versa (Garrido, Kilnar, Stephan & Fritson, 2009; Moreau et al., 2013). The purpose of the current study was therefore to explore the neural mechanisms involved in speech versus non-speech processing in infants by actually presenting infants with speech and closely matched non-speech stimuli. A match/mismatch event-related potential (ERP) paradigm was used to investigate the time-course of speech processing in the brain. Within infancy and childhood, early and late going components have been identified which are key to auditory processing (Kushnerenko, Ceponiene, Balan, Fellman, Huotilainen & Naatanen, 2001). Barnet (1975) identified two key components, the P2 (100-300ms) and the N2 (500ms). Both peaks are believed to reflect auditory sensory processing, with the earlier P2 being identified as primarily a perceptual processing component (Ceponiene, Rinne, & Naatanen, 2002) and the later N2 component believed to play a role in the early cognitive evaluation of auditory stimuli (Ceponiene et al., 2002; Kushnerenko et al., 2001).

To explore the neural mechanisms involved in speech versus non-speech processing and detection in the current study, several pairs of stimuli were deployed from the same category (e.g., Speech /ba/ followed by Speech /da/) or from different categories (e.g., Speech /ba/ followed by Non-Speech analogue of /da/). As this procedure was employed for both speech and non-speech stimuli, it allowed for the examination of match and mismatch mechanisms for speech versus non-speech processing. In addition, this method also allowed for the comparison of the time-course and lateralisation associated with the processing of these two categories of stimuli relative to one another. In order to further ensure that mechanisms were truly related to perceptual versus sensory aspects of the categorization of speech versus non-speech, speech and non-speech stimuli were carefully matched to one another in terms of their physical characteristics (Ceponiene, Torki, Alku, Koyama, & Townsend, 2008). Finally, to avoid the potential influence of task demands in driving speech lateralisation (Hickok & Poeppel, 2007; Scott & Wise, 2002), a task-less experimental procedure was used to ensure that the natural passive processing of speech versus non-speech stimuli was examined.

Three hypotheses were formed based on the previous literature on speech processing in infancy. Firstly, that left lateralisation would be seen in response to speech stimuli in the temporal and frontal regions. Although the previous literature is mixed and limited, researchers believe that infants are born with left hemisphere superiority for processing speech (Peña et al., 2003). Previous studies have found left activation in temporal areas when infants are presented with speech (Dehaene-Lambertz et al., 2002; Minagawa-Kawai et al., 2010) and other studies have reported a specialisation of the left hemisphere for language processing in infancy (Kotilahti et al, 2010; Pang et al., 1998). Furthermore, neuroimaging studies in adults have also demonstrated left lateralisation during language processing, with the frontal and temporal cortices playing an important role (Dronkers et al., 2004; Hickok & Poeppel, 2007; Keller et al., 2009; Price, 2010).

Secondly, as match/mismatch paradigm was used it was hypothesised that a mismatch response would be observed when the second stimulus presented was not from the same category (speech, non-speech) as the first stimulus in the presented pair. This was hypothesised as differences in brain activation have been found when speech is presented

(Dronkers et al., 2004; Hickok & Poeppel, 2007; Keller et al., 2009; Price, 2010). It was therefore hypothesised that a mismatch effect would be present when speech stimuli were presented along with non-speech, potentially in the left hemisphere as this region has been found to play an important role in language processing (Dronkers et al., 2004; Hickok & Poeppel, 2007; Keller et al., 2009; Price, 2010).

Thirdly, it was predicted that speech would be processed faster in comparison to the non-speech stimuli in the frontal regions of the brain as found by Dehaene-Lambertz and colleagues (2006). A final hypothesis was not formed about the time-course of speech processing in infancy due to the limited research in this area (Dehaene-Lambertz, 2002; Vouloumanos & Werker, 2007), in addition to the fact that previous fMRI and fNIRS methodologies have poor temporal resolution in comparison to the current study. However, as previously discussed, the literature has identified key early and late going components which are associated with early perceptual processing and cognitive evaluations of stimuli (Barnet, 1975; Ceponiene et al., 2002; Kushnerenko et al., 2001). Based on this literature, if an earlier component is found for speech processing it would be interpreted as a perceptual response to the stimuli, if a later going component is found it would be interpreted as a cognitive evaluation of the stimuli. If both early and late going components are found then this would be interpreted as both perceptual and cognitive evaluations of the stimuli being involved in speech processing.

.

`3.3. METHOD

3.3.1. Participants

Participants were infants aged between three and five months who had been recruited via the Infant and Child Laboratory at the University of Birmingham (see chapter 2: General Methodology, section 2.2.1. for further detail on recruitment). Parents provided written consent for their child to participate after having the study explained to them by the experimenter. Infants received a small toy for taking part, and parents received £10 to cover expenses for travelling to the University-based laboratory.

EEG data were collected from thirty participants. Previous studies using MMN paradigms rely on as few as 10% of ERP trials for their primary data (Dehaene-Lambertz, 2000; Dehaene-Lambertz and Baillet, 1998; Pang et al., 1998) and therefore rely on fewer viable trails for data analysis. The current study selected 50 viable ERP trials as a minimum requirement for inclusion of data as this study adopts a more balanced paradigm (as discussed in the introduction). Therefore, a higher amount of viable trials were included per infant to reflect the quality of data collected using this paradigm. As a result, prior to statistical analysis twelve infants were excluded for having fewer than 50 trials in any condition, Table 3.1 displays the average amount of viable ERP trials included per condition in addition to the average amount of trials presented to infants.

A further six infants were excluded from analysis due to a software error which resulted in corrupted files. Thus, the final sample included twelve infants (5 female), with a mean age of 145 days (SD: 29.30).

Table 3.1

Average amount of viable trials included, for each condition with standard deviations (SD).

	Speech		**Non-Speech**	
	Match	**Mismatch**	**Match**	**Mismatch**
Average good trials	105 (40.4)	100 (41.8)	99 (35.8)	102 (37.8)
Average total trials	417 (50.1)	413 (53.2)	416 (50.1)	416 (50.1)
Average percentage of trials included	25%	24%	23%	25%

3.3.2. Stimuli

The stimuli for this study were a subset of those used by Ceponiene and colleagues (2008), which were created using the semi-synthetic speech generation method (SSG) as described by Ceponiene et al. (2008). This method allows for the accurate modification of natural speech. The SSG method begins by extracting, from a natural utterance, a glottal excitation waveform, generated by the fluctuating vocal folds. This is then used to excite an artificial vocal tract model, specific to the phoneme to be created. By using natural glottal excitation, a realistic prosody and jitter is achieved in the periodic structure of the synthesised waveform (Alku, Tiitinen. & Näätänen,1999).

For the current study, three consonant-vowel (CV) syllables, /ba/, /da/, and /ga/, spoken by a female speaker of English, were recorded, digitized, and used as a raw material for computing the SSG. Processed were the glottal excitation waveform, the formant frequencies for the three voiced plosive consonants (/b/, /d/, /g/), as well as formant frequencies for the vowel /a/. The consonant burst section of the syllables was copied from the original recordings. A 30 ms pre-consonant voice bar, present in the natural /ba/ syllables, was also added to the /da/ and /ga/ stimuli to make the gross structure of all stimuli identical. Using these parameters, the semi-synthetic syllables were processed through an adaptive digital vocal tract filter, formant frequencies of which changed linearly from those estimated from the consonant bursts to the settings estimated from the vowel. The consonant burst duration was 10 ms. The consonant-to-vowel transition (CVT, from the end of the consonant burst to the beginning of the steady-state vowel) was 80 ms in duration. The CVT segment was followed by an identical steady-state vowel /a/ lasting for 60 ms. Therefore, the total durations of the syllable and non-phonetic correlate stimuli were 180 ms; a pre-voicing of 30 ms, consonant burst of 10 ms, CVT of 80 ms, and a steady-state vowel lasting 60 ms. Since the same glottal excitation was used in the synthesis of all syllables, the stimuli only differed acoustically in terms of the plosives and formant transitions. The rest of the sound features (fundamental frequency, intonation, phonation type, intensity duration) were kept equal.

The non-phonetic correlates of the three syllables were created from five sinusoidal tones. The frequencies and intensity levels of the tones were selected on the basis of the formant frequencies of the syllables, as computed by the SSG; the lowest tone of each non-phonetic stimulus was selected to match the fundamental frequency of the underlying syllable, while the rest of the four sinusoidals matched the harmonic component in the vicinity of the four lowest formants in the spectrum of the corresponding syllable. The burst sections were synthesised to match the spectra of the corresponding burst sections in the syllables. Finally, the shapes of the burst-to-steady state formant transitions, the durations, and intensities of the non-phonetic stimuli were equalised to those of the corresponding speech stimuli (see Ceponiene, Torki, Alku, Koyama, & Townsend, 2008).

3.3.3. Procedure

In total, six different stimuli were used in this study; three “speech” syllables (/ba/, /da/, and /ga/), and their three non-phonetic “non-speech” correlates. There were four conditions: Speech Repeated, Speech Non-Repeated, Non-Speech Repeated, and Non-Speech Non-Repeated. Table 3.1 includes information on the average amount of trials presented to participants. Each trial consisted of two stimuli presented with an inter-stimulus interval of 50 ms. The second stimulus in the trial was followed by an inter-trial interval that varied between 475, 550, and 625 ms. The trials were presented pseudo-randomly using E-Prime software (Psychology Software Tools Inc., Pittsburgh, Pennsylvania).

Infants were seated on their mother’s lap and were entertained throughout the study via silent play with several experimenters. Stimuli were presented in a sound attenuated room via stereo speakers with a sound pressure level of 60 dB measured from the seated participant’s head. Stimulus presentation and EEG recording lasted approximately 30 minutes. The EEG was stopped for eight infants who became distressed during the study (five of these infants contributed to the twelve infants who were excluded from analysis for having less than 50 trials in any condition).

3.3.4. EEG Recording

EEG was recorded continuously using a 128-channel Hydrocel Geodesic Sensor Net (HCGSN; Electrical Geodesics, Inc., Eugene, Oregon; Tucker, 1993), referenced to a single vertex electrode, Cz (sample rate = 500 Hz; online highpass filter = 0.1 Hz). Electrode impedances were kept below 100 KOmega. EEG recordings were processed offline using Netstation 4.3.1. software (Electrical Geodesics, Inc., Eugene, Oregon). The data were filtered (highpass filter = 0.1 Hz, 50Hz Notch) and segmented to epochs beginning 100 ms before and continuing 800 ms after the presentation of the second auditory stimulus in the trial. Data were processed using an artifact detection tool that marked channels bad if the max-min threshold exceeded 100 mV, if eye-blinks occurred (threshold max-min > 100) and/or if eye movements occurred (threshold max-min > 55.00). Individual electrodes were marked bad for the entire recording if they presented with artifacts for 20% of the trials or more. By-hand artifact detection was then conducted by a trained observer to mark individual trials bad if they contained more than 12 bad channels, eye blinks, and/or eye movements. Following this, bad channels in the data were replaced using a spherical spline interpolation algorithm (Srinivasan, et al., 1996). The data were then averaged for each participant, and the 128-electrodes were re-referenced to an average reference and then baseline corrected to a 100 ms pre-stimulus interval.

3.3.5. Electrodes

The frontal-central and temporal regions were initially identified as previous research on speech processing in adults and infants have implicated these areas in language processing (Dehaene-Lambertz et al., 2002; Lambertz et al., 2006; Dehaene-Lambertz, 2000; Dehaene-Lambertz & Dehaene, 1994 ; Dehaene-Lambertz & Baillet, 1998; Pang et al., 1998; Dronkers et al., 2004; Price, 2010; Hickok & Poeppel, 2007; Keller et al., 2009). Electrodes were later selected by visually inspecting the data, to identify possible amplitude differences prior to statistical analysis. Electrodes used to measure frontal-central electrodes consisted of three electrode montages combined: left-frontal-central (see figure 3.1.), central-frontal-central (see figure 3.2.) and right-frontal-central (see figure 3.3.). Electrodes used to measure the left and right temporal component are shown in figure 3.4. Mean amplitudes were measured for each individual electrode in the relevant montages, and then averaged within relevant regions for each participant.

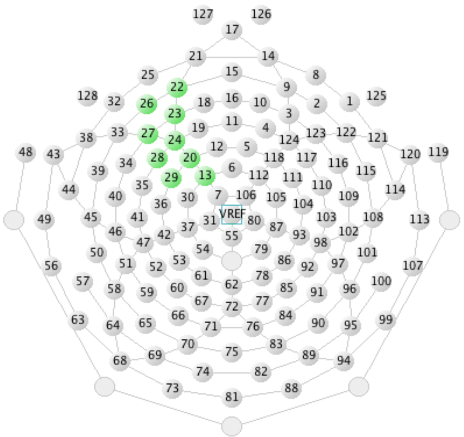

Figure 3.1. Left-frontal-central electrodes

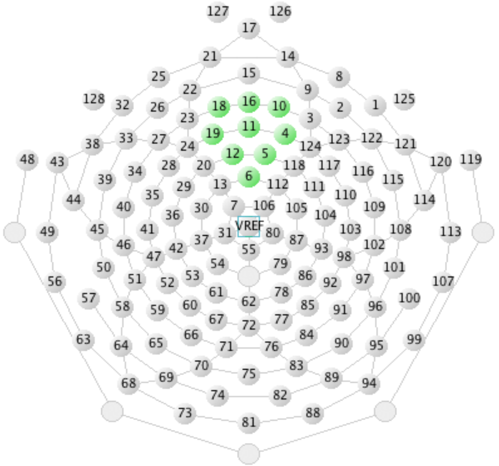

Figure 3.2. Central-frontal-central electrodes

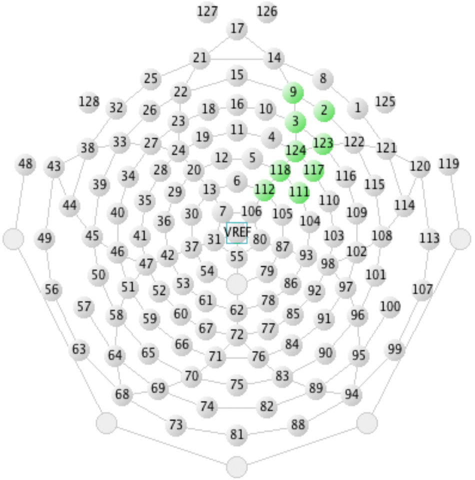

Figure 3.3. Right-frontal-central electrodes

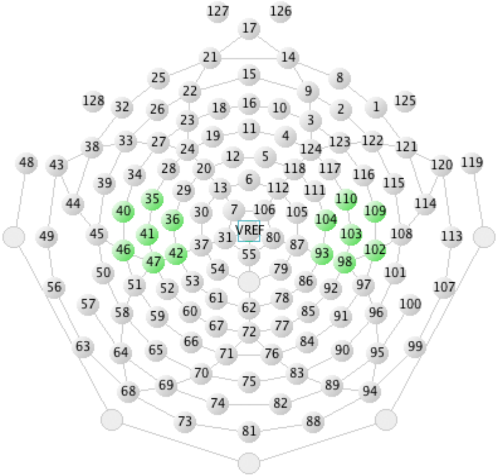

Figure 3.4. Temporal electrodes

3.4. RESULTS

3.4.2. ERP Components

Three ERP components were identified. The first was an early positive-going component peaking for speech and non-speech at approximately 200 ms (P200) over frontal-central electrodes. The second was a middle latency component peaking around 200 ms also in the frontal-central electrodes. The final component peaked around 500 ms (P500) over temporal electrodes and also in the frontal-central electrodes. Time windows utilized for each component were as follows: Frontal-Central P200 and latency: 100-300 ms; Temporal and Frontal-Central P500: 400-600 ms. Time windows were selected based on previous ERP studies which have explored perceptual processing in infancy (Barnet, 1975; Ceponiene et al., 2002; Kushnerenko et al., 2001). Additionally, a visual inspection of the grand average data was also performed to ensure peaks were contained within the selected timeframes.

3.4.3. Frontal-Central P200 analysis

3.4.3.1. Test of Normality

A Shapiro-Wilk test of normality was performed on the P200 data for the frontal-central region. All groups returned non-significant results (see table 3.2.), indicating the data were normally distributed. A parametric test was therefore performed. Please see table 3.6. for average amplitudes.

Table 3.2.

Shapiro-Wilk p-values for the P200 speech and non-speech data by hemisphere and repetition for the frontal-central region.

	Left		Right	
Repetition	**Speech**	**Non-Speech**	**Speech**	**Non-Speech**
Match	0.202	0.899	0.132	0.193
Mismatch	0.961	0.782	0.156	0.124

A 3-way ANOVA was performed to explore the mismatch effect across frontal-central regions for speech and non-speech processing. Stimulus (speech, non-speech), repetition (match, mismatch) and region (left, centre and right) were included as within-subject factors. No main effect of stimulus (F (1, 11) = 1.453, p = 0.253, $n^2 = 0.117$) or repetition (F (1, 11) = 1.296, p = 0.279, $n^2 = 0.105$) was found. However, a main effect of region was (F (2, 22) = 6.324, p<0.01, $n^2 = 0.365$). Paired t-tests revealed greater amplitude for the frontal-central region over the left-frontal-central region (t (11) = -7.269, p<0.01) and over the right-frontal-central region (t (11) = 9.958, p<0.001), but so significant differences were seen between the left-frontal-central and right-frontal-central regions (t (11) = -0.258, p = 0.801). Significant interactions were not found for stimulus and region (F (2, 22) = 0.480, p = 0.625, $n^2 = 0.042$) or repetition and region (F (2, 22) = 1.020, p = 0.377, $n^2 = 0.085$). Therefore, speech and non-speech stimuli were not associated with greater activation in differing frontal regions, furthermore, overall mismatch effects were not greater in any particular region. However, the analysis did reveal a significant interaction for stimulus and repetition (F (1, 11) = 15.690, p<0.01, n² = 0.588) which was explored further using a 2-way ANOVA in the section below.

3.4.3.2. 2-way ANOVA for P200 stimulus by repetition interaction

A 2-way analysis of variance (ANOVA) was performed on the mean amplitude data for the early frontal-central component to explore match and mismatch effects for speech and non-speech. Stimulus (speech, non-speech) and repetition (match, mismatch) were included as within-subject factors. No main effect of stimulus (F (1, 11) = 1.453, p = 0.253, n² = 0.117) or repetition (F (1, 11) = 1.296, p = 0.279, n² = 0.105) was found. The interaction of the two factors was significant (F (1, 11) = 15.690, p<0.05, n² = 0.588). Paired t-tests revealed a significant effect of repetition for the speech condition, whereby the difference between matched and mismatched speech stimuli was greater for speech (t (11) = -3.061, p<0.05) than it was for the non-speech condition (t (11) = 1.803, p = 0.099) as shown in and figure 3.5 and figure 3.6.

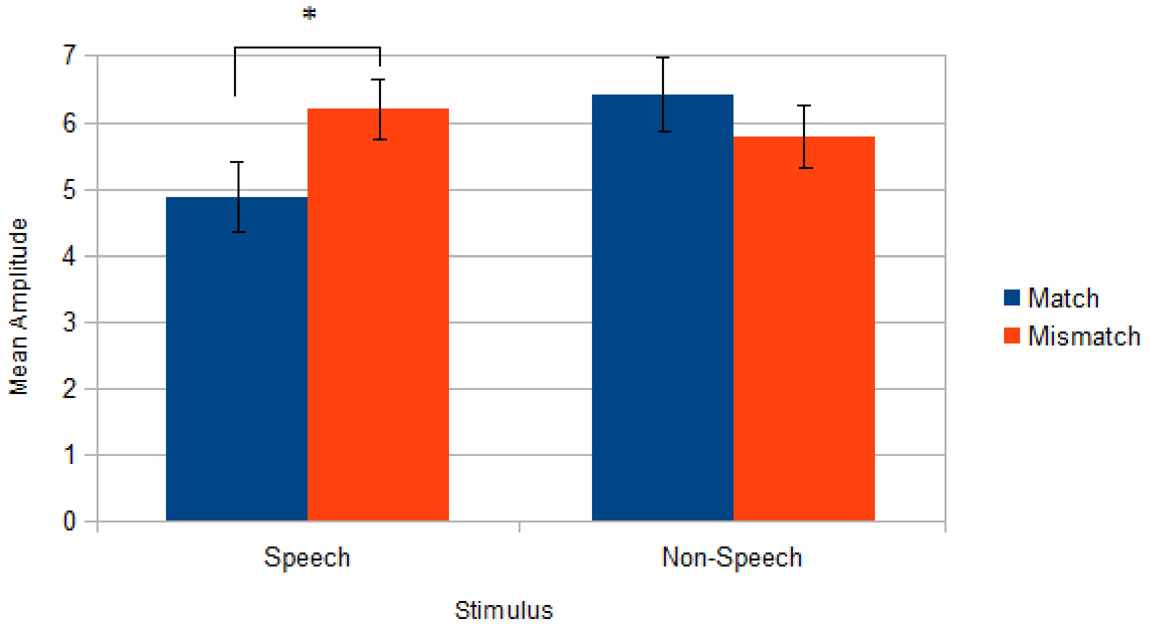

Figure 3.5. Mean amplitude in microvolts for speech and non-speech stimuli in the frontal-central region for matched and mismatched conditions. Error bars represent the standard error of the means. Note: * indicates that the mismatch effect was significantly larger for speech ($p<0.05$).

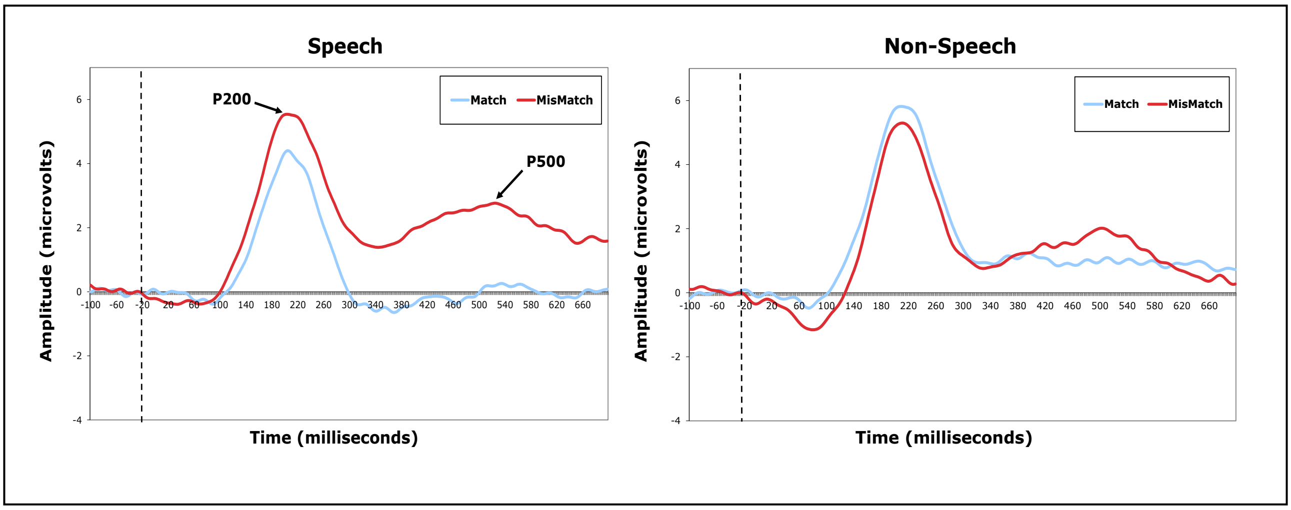

Figure 3.6. Match and Mismatch waveforms recorded over the frontal cortex for speech and non-speech.

A 3-way interaction was also revealed for stimulus, repetition, and region ($F(2, 22) = 2.293$, $p<0.01$, $n^2 = 0.301$). To investigate this interaction three further ANOVAs were conducted. The first for the left-frontal-central region with stimulus (speech, non-speech) and repetition (match, mismatch) as within-subject factors. The second for the centre-frontal-central region, again with stimulus (speech, non-speech), and repetition (match and mismatch) as within-subject factors. The third for the right-frontal-central region, which also had stimulus (speech, non-speech) and repetition (match and mismatch) as within-subject factors.

3.4.3.3. Left-frontal-central P200

No main effect of stimulus (F (1, 11) = 2.567, p = 0.137, n^2 = 0.189) or repetition (F (1, 11) = 0.844, p = 0.378, n^2 = 0.071) was found for the left-frontal-central region. The interaction of these factors was significant (F (1, 11) = 19.725, $p<0.05$, n^2 = 0.642). Paired t-tests revealed a significant difference between matched and mismatched stimuli in the speech condition (t (11) = -3.018, $p<0.05$), this effect was not found in the non-speech condition (t (11) = 1.459, p = 0.173) as shown in figure 3.7.

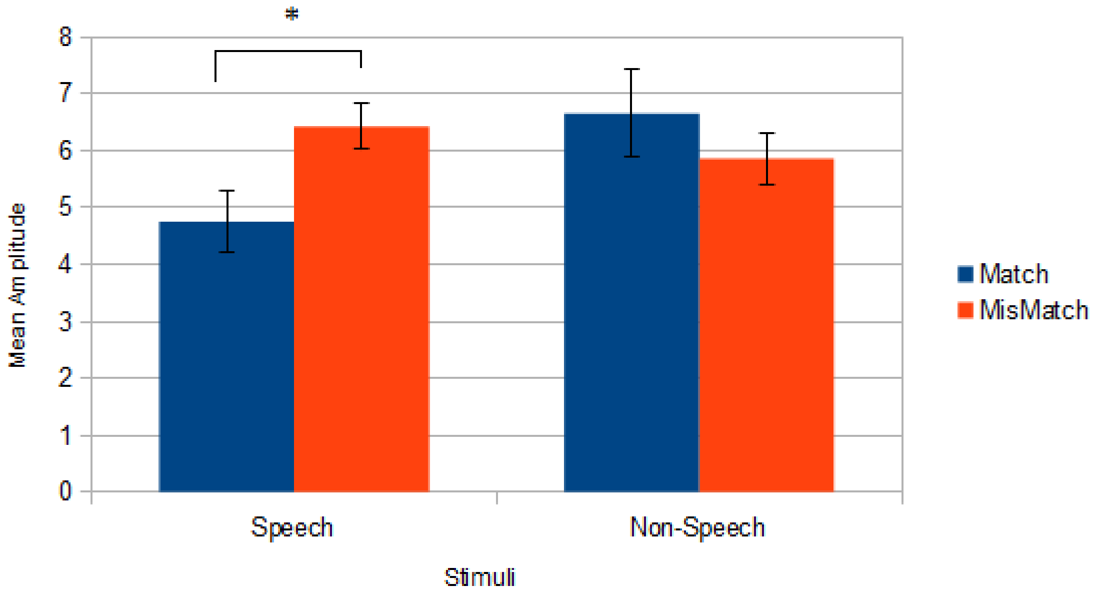

Figure 3.7. Mean amplitude in microvolts for speech and non-speech stimuli in the left-frontal-central region for match and mismatch conditions for the P200 component. Error bars represent the standard error of the means. Note: * indicates significant interaction, that the mismatch effect was significantly larger for speech stimuli ($p<0.05$).

3.4.3.4. Centre-frontal-central P200

No main effect of stimulus (F (1, 11) = 1.509, p = 0.245, n² = 0.121) or repetition (F (1, 11) = 0.015, p = 0.905, n² = 0.001) was found . A significant interaction was found between stimulus and repetition (F (1, 11) = 14.071, p<0.01, n² = 0.561). Paired t-tests revealed a significant difference between matched and mismatched stimuli in the speech condition (t (11) = -2.794, p<0.05) but not for the non-speech condition (t (11) = 2.279, p = 0.076) as shown in figure 3.8.

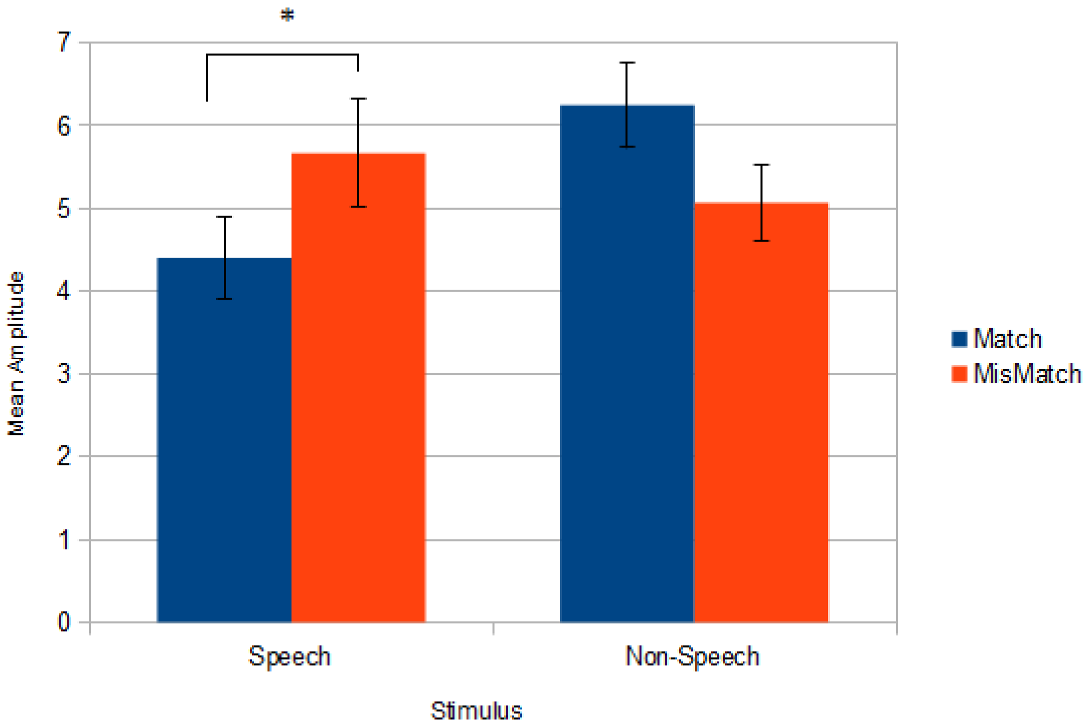

Figure 3.8. Mean amplitude in microvolts for speech and non-speech stimuli in the central-frontal-central region for match and mismatch conditions for the P200 component.

Error bars represent the standard error of the means. Note: * indicates significant interaction, that the mismatch effect was significantly larger for speech stimuli ($p<0.05$).

3.4.3.5. Right-frontal-central P200

No main effect of stimulus ($F (1, 11) = 0.535$, $p = 0.480$, $n^2 = 0.121$) or repetition ($F (1, 11) = 4.653$, $p = 0.064$, $n^2 = 0.297$) was found. Additionally, no significant interaction was found between stimulus and repetition ($F (1, 11) = 2.782$, $p = 0.124$, $n^2 = 0.202$).

3.4.4. P200 Latency Component

3.4.4.1. Test of Normality

A Shapiro-Wilk test of normality was performed on the P200 latency data for the frontal-central region. All groups returned non-significant results (see table 3.3.), indicating the data were normally distributed. A parametric test was therefore performed. Please see table 3.6. for average latency values.

Table 3.3.

Shapiro-Wilk p-values for the P200 speech and non-speech latency data by repetition in the frontal-central region.

Repetition	**Speech**	**Non-Speech**
Match	0.260	0.258
Mismatch	0.133	0.240

To explore timing differences in speech processing a 3-way ANOVA was conducted with region (left, centre and right) stimulus (speech, non-speech) and repetition (match, mismatch) as within-subject factors. No main effect of stimulus (F (1, 11) = 0.050, p = 0.828, $n^2 = 0.004$), region (F (2, 22) = 1.291, p = 0.295, $n^2 = 0.105$) or repetition was found (F (1, 11) = 0.577, p = 0.464, $n^2 = 0.050$). The interaction of stimulus and repetition (F (1, 11) = 2.864, p = 0.119, $n^2 = 0.207$), stimulus and region (F (2, 22) = 1.904, p = 0.173, $n^2 = 0.148$)

and region and repetition (F (2, 22) = 0.531, p = 0.595, n² = 0.046) were also not significant . Therefore there were no significant differences in the speed at which speech and non-speech were processed for the match or mismatch conditions for any of the regions.

3.4.5. P500 Frontal-Central

3.4.5.1. Test of Normality

A Shapiro-Wilk test of normality was performed on the dataset for the P500 frontal-central component data. All groups returned non-significant results (see table 3.4.), indicating the data were normally distributed. A parametric test was therefore performed. Please see table 3.6. for average amplitudes.

Table 3.4.

Shapiro-Wilk p-values for the P500 speech and non-speech stimuli by repetition in the frontal-central region.

Repetition	**Speech**	**Non-Speech**
Match	0.699	0.090
Mismatch	0.793	0.647

A 3-way ANOVA was performed to explore the mismatch effect across frontal-central regions for speech and non-speech processing. Stimulus (speech, non-speech), repetition (match, mismatch) and region (left, centre, right) were included as within-subject factors. No main effect of stimulus (F (1, 11) = 0.042 p = 0.841, n^2 = 0.004) or region (F (2, 22) = 1.100, p = 0.351 n^2 = 0.091) was found. However, a main effect of repetition was discovered (F (1, 11) = 23.656, $p<0.01$, n^2 = 0.683). Paired t-tests revealed greater amplitude for the mismatch stimuli in comparison to the matched stimuli (t (11) = -4.864, $p<0.01$). Significant interactions were not found for stimulus and region (F (2, 22) = 0.155 p = 0.857, n^2 = 0.014) or repetition and region (F (2, 22) = 3.611 p = 0.739, n^2 = 0.027). Therefore, speech and non-speech stimuli were not associated with greater activation in differing frontal regions. Furthermore, overall mismatch effects were not greater for any particular region. However, the analysis did reveal a significant interaction for stimulus and repetition (F (1, 11) = 5.077, $p<0.05$, n^2 = 0.316) which was explored further using a 2-way ANOVA, as shown below.

3.4.5.2. 2-way ANOVA for P500 stimulus by repetition interaction

A 2-way ANOVA with stimulus (speech, non-speech) and repetition (match, mismatch) as within-subject factors was performed on the mean amplitude data to explore match and mismatch effects for speech and non-speech. No main effect of stimulus was found (F (1, 11) = 0.042, p = 0.841, n^2 = 0.004). A main effect of repetition was found (F (1, 11) = 23.656, $p<0.001$, n^2 = 0.683) which showed a greater effect for mismatched stimuli. A significant interaction was revealed for the two factors (F (1, 11) = 5.077, $p <0.05$, n^2 = 0.316). Paired t-tests revealed a significant mismatch effect for the speech stimuli as seen in figure 3.9. and figure 3.6. (t (11) = -5.208, p<0.001) this effect was not seen in the non-speech stimuli (t (11) = -1.033, p = 0.324).

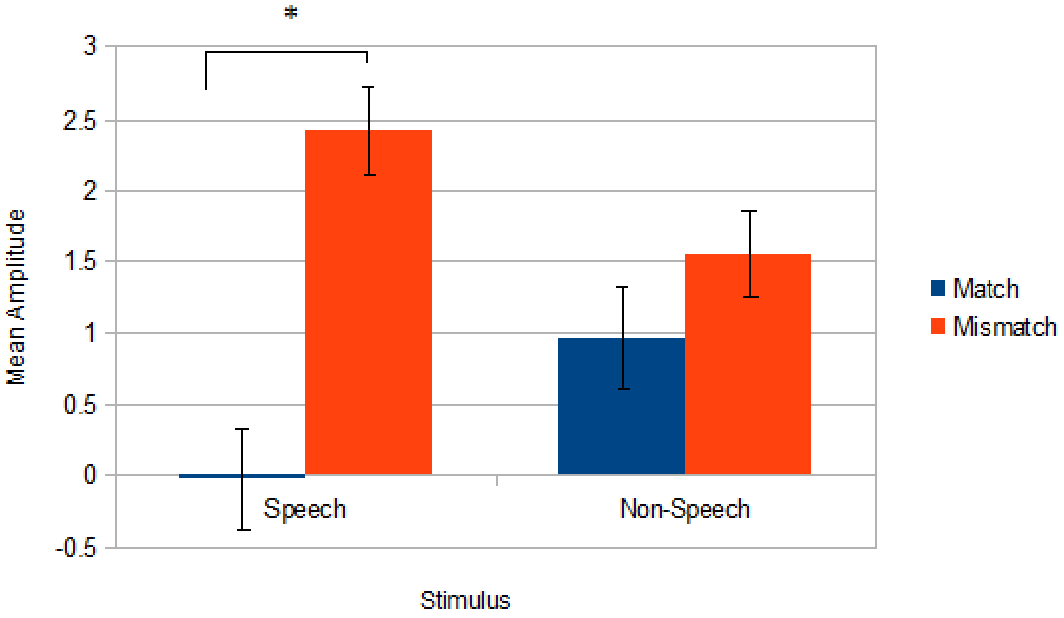

Figure 3.9. Mean amplitude in microvolts for speech and non-speech stimuli in the frontal-central region for match and mismatch conditions for the P500. Error bars represent the standard error of the means. Note: * represents the significant interaction, showing that the mismatch effect was significantly larger for speech (p<0.01).

A 3-way interaction was also revealed for stimulus, repetition and hemisphere (F (2, 22) = 2.293, p<0.01, n² = 0.301). To investigate this interaction three further ANOVAs were conducted for each region (left-frontal-central, centre-frontal-central, right-frontal-central) with stimulus (speech, non-speech) and repetition (match, mismatch) as within-subject factors.

3.4.5.3. Left-frontal-central P500

No main effect of stimulus (F (1, 11) = 0.065, p = 0.804, $n^2 = 0.006$) was found. A main effect of repetition (F (1, 11) = 12.504, p<0.01, $n^2 = 0.532$) was discovered for the left-frontal-central region. Paired t-test found a greater amplitude for the mismatched stimuli over the matched stimuli (t (11) = -3.536, p<0.05). The interaction of the factors was also significant (F (1, 11) = 7.896, p<0.05, $n^2 = 0.418$). Paired t-tests showed a significant difference between matched and mismatched stimuli for the speech condition (t (11) = -4.331, p<0.01) but not for the non-speech condition (t (11) = -0.259, p = 0.801) as shown in figure 3.10.

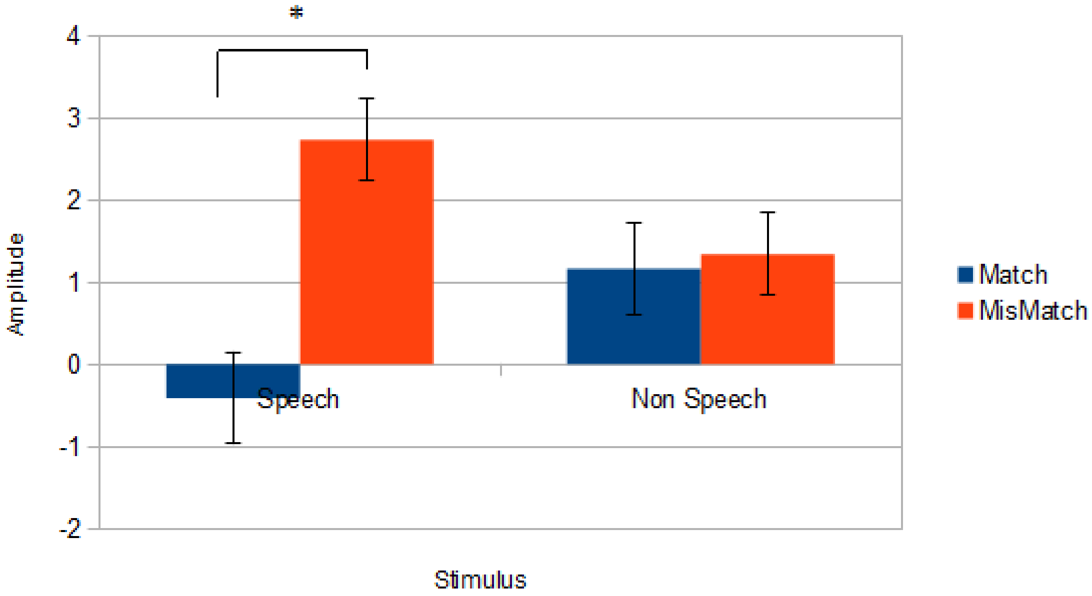

Figure 3.10. Mean amplitude in microvolts for speech and non-speech stimuli in the left-frontal-central region for match and mismatch conditions for the P500 component. Error bars represent the standard error of the means. Note: * indicates significant interaction, that the mismatch effect was significantly larger for speech (p<0.01).

3.4.5.4. Centre-frontal-central P500

No main effect of stimulus (F (1, 11) = 0.145 p = 0.711, n² = 0.013) was found. The analysis revealed a significant main effect of repetition (F (1, 11) = 17.543, p<0.01, n² = 0.615). Paired t-tests showed greater amplitude for the mismatch stimuli in comparison to the matched stimuli (t (11) = -4.188, p<0.01). A significant interaction was not found for stimulus and repetition (F (1, 11) = 3.684, p = 0.081, n² = 0.251).

3.4.5.5. Right-frontal-central P500

The analysis did not reveal a main effect of stimulus (F (1, 11) = 0.011, p = 0.920, n^2 = 0.001). A main effect of repetition (F (1, 11) = 28.520, p<0.01, n^2 = 0.722) was found. Paired t-tests revealed a significantly greater mismatch effect (t (11) = -5.340, p<0.01). Additionally, no significant interaction was found between stimulus and repetition (F (1, 11) = 0.613, p = 0.450 n^2 = 0.053).

3.4.6. P500 Temporal Component

3.4.6.1. Test of Normality

A Shapiro-Wilk test of normality was performed on the dataset for the P500 temporal component data. All groups returned non-significant results (see table 3.5.), indicating the data were normally distributed. A parametric test was therefore performed. Please see table 3.6. for average amplitudes.

Table 3.5.

Shapiro-Wilk p-values for the P500 speech and non-speech data by hemisphere and repetition for the temporal region.

	Left		**Right**	
Repetition	**Speech**	**Non-Speech**	**Speech**	**Non-Speech**
Match	0.401	0.379	0.340	0.866
Mismatch	0.446	0.808	0.979	0.136

A 3-way ANOVA was performed to explore the mismatch effect across hemispheres for speech and non-speech processing. Stimulus (speech, non-speech), repetition (match, mismatch) and region (left, right) were included as within-subject factors. No main effect of stimulus ($F (1, 11) = 1.820$, $p = 204$, $n^2 = 0.142$) or region ($F (1, 11) = 1.446$, $p = 0.254$, $n^2 = 0.116$) was found. However, a main effect of repetition was ($F (1, 11) = 24.461$, $p<0.001$, $n^2 =$

0.690). A paired t-test revealed an overall greater effect for the mismatch stimuli (t (11) = -4.946, p<0.001). Significant interactions were not found for stimulus and region (F (1, 11) = 1.622, p = 0.229, n² = 0.128) or repetition and region (F (1, 11) = 0.020, p = 0.889, n² = 0.002). Therefore, speech and non-speech stimuli were not associated with greater activation in differing temporal hemispheres, furthermore, overall mismatch effects were not greater in either hemisphere. The 3-way ANOVA did reveal a significant interaction for stimulus and repetition (F (1, 11) = 8.660, p<0.05, n² = 0.440). Paired t-tests revealed a significant difference between the matched and mismatched stimuli in the speech condition (t (11) = -5.265, p<0.001) this difference was not found in the non-speech condition (t (11) =-0.727, p = 0.483) as shown in figure 3.11 and figure 3.12.

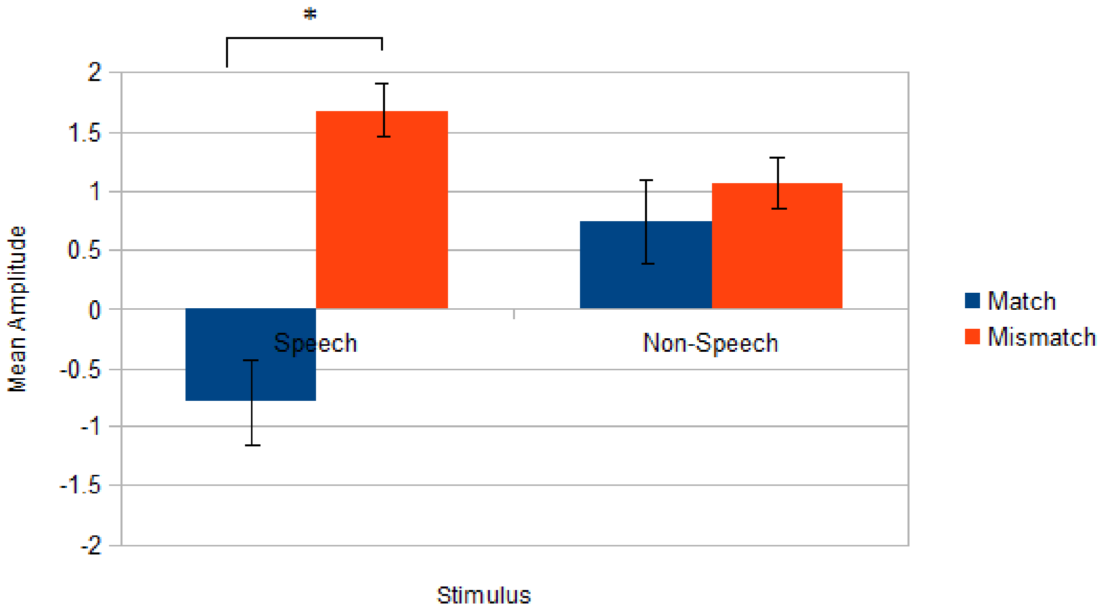

Figure 3.11. Mean amplitude in microvolts for speech and non-speech stimuli in the temporal region for match and mismatched stimuli. Error bars represent the standard error of

the means. Note: * indicates that the mismatch effect was significantly larger for speech ($p<0.001$).

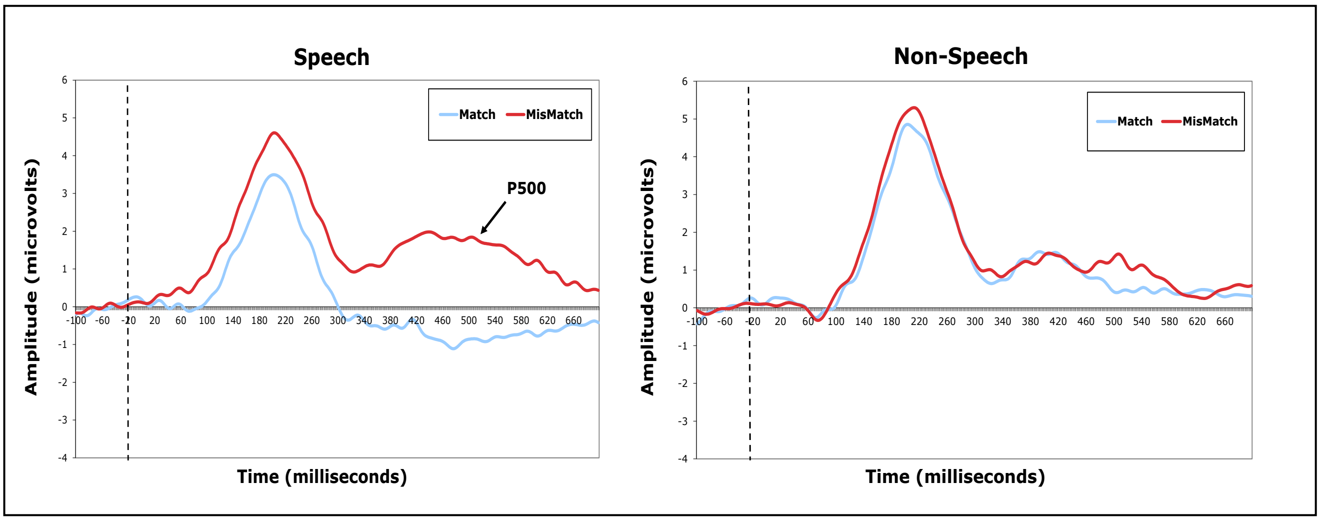

Figure 3.12. Match and Mismatch waveforms recorded over the temporal cortex for speech and non-speech in infants.

A 3-way interaction was also revealed for stimulus, repetition and hemisphere ($F(1, 11) = 23.311$, $p<0.01$, $n^2 = 0.679$). To investigate this interaction two further ANOVAs were conducted. The first for the left temporal hemisphere with stimulus (speech, non-speech) and repetition (match, mismatch) as within-subject factors. The second for the right temporal hemisphere, again with stimulus (speech, non-speech) and repetition (match, mismatch) as within-subject factors.

3.4.6.2. Left Temporal P500

No main effect of stimulus was found for the left temporal region (F (1, 11) = 3.864, p = 0.075, n^2 = 0.260). A main effect of repetition was discovered (F (1, 11) = 10.383, p<0.01, n^2 = 0.486), a paired t-test revealed an overall greater effect for the mismatched stimuli (t (11) = -3.222, p<0.01). A significant interaction was also found for stimulus and repetition (F (1, 11) = 14.352, p<0.01, n^2 = 0.566). Paired t-tests revealed a significant difference between matched and mismatched stimuli in the speech condition (t (11) = -4.647, p<0.01), this effect was not found in the non-speech condition (t (11) = -4.647, p<0.01) as shown in figure 3.13.

3.4.6.3. Right Temporal P500

No main effect of stimulus was found for the right temporal region (F (1, 11) = 0.175, p = 0.684, n^2 = 0.016). A main effect of repetition was found (F (1, 11) = 10.297, p<0.01, n^2 = 0.483). A follow-up paired t-test showed an overall greater effect for the mismatched stimuli (t (11) = -3.209, p<0.01). No significant interaction was found for stimulus and repetition (F (1, 11) = 0.650, p = 0.437, n^2 = 0.056) as shown in figure 3.13.

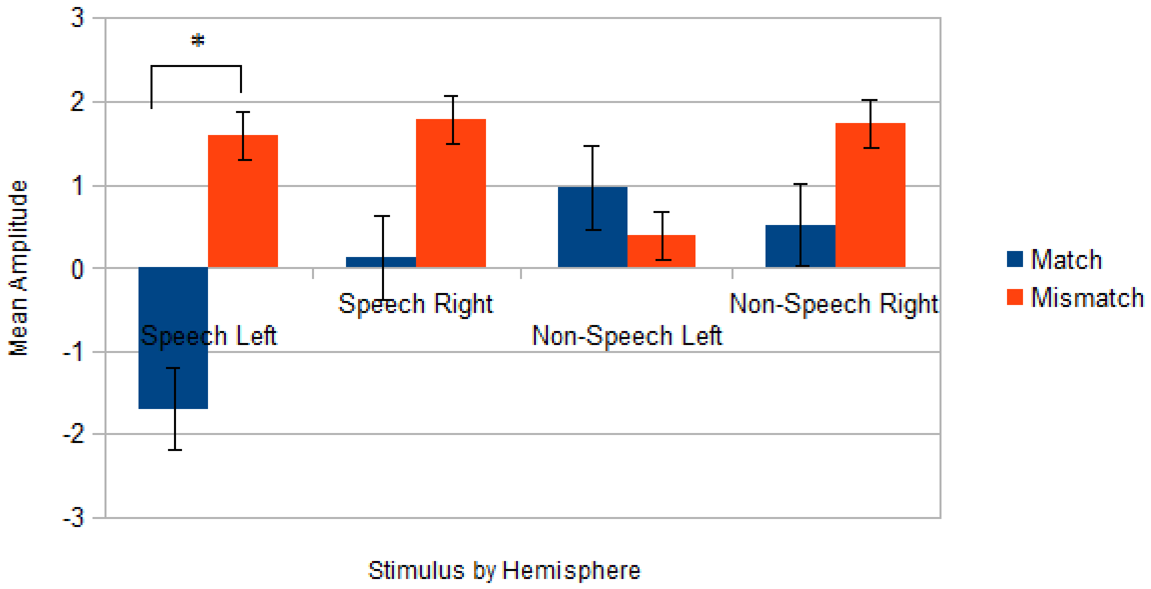

Figure 3.13. Mean amplitude in microvolts for speech and non-speech stimuli in the left and right temporal regions for match and mismatched stimuli. Error bars represent the standard error of the means. Note: * indicates that the significant mismatch interaction for speech in the left temporal region (p<0.01).

Table 3.6

Average amplitude values (*SD*) for the frontal-central P200 component, P200 latency component, P500 frontal-central and temporal component.

P200 Frontal-Central Component

	Left		Right	
Repetition	**Speech**	**Non-Speech**	**Speech**	**Non-Speech**
Match	4.96 (*1.9*)	6.65 (*2.6*)	5.77 (*2.1*)	6.36 (*1.4*)
Mismatch	6.42 (*1.3*)	5.85 (*1.5*)	6.52 (*1.6*)	6.45 (*1.9*)

P200 Frontal-Central Latency Component

	Left		Right	
Repetition	**Speech**	**Non-Speech**	**Speech**	**Non-Speech**
Match	105.16 (*8.4*)	105.68 (*9.0*)	104.17 (*7.6*)	106.29 (*7.3*)
Mismatch	107.93 (*14.2*)	104.80 (*5.7*)	103.97 (*10.5*)	104.86 (*4.9*)

P500 Frontal-Central Component

	Left		Right	
Repetition	**Speech**	**Non-Speech**	**Speech**	**Non-Speech**
Match	-0.23 (*2.4*)	0.73 (*2.5*)	0.66 (*1.6*)	0.63 (*1.8*)
Mismatch	0.91 (*6.8*)	1.43 (*1.7*)	0.33 (*7.4*)	2.02 (*2.2*)

P500 Temporal Component

	Left		Right	
Repetition	**Speech**	**Non-Speech**	**Speech**	**Non-Speech**
Match	-1.24 (*2.2*)	0.81 (*2.2*)	0.02 (*1.7*)	0.48 (*1.8*)
Mismatch	-0.24 (*6.9*)	0.68 (*2.4*)	-0.03 (*6.9*)	1.79 (*2.3*)

3.5. DISCUSSION

Little is currently known about the neural mechanisms which underlie speech processing in infancy, further research is needed to enable researchers to understand the development of language mechanisms in the brain. (Dehaene-Lambertz, 2002; Vouloumanos & Werker, 2007). The present study was designed to examine the time-course and neural mechanisms involved in the processing of speech versus non-speech stimulus categories in infancy. Based on previous research three distinct hypotheses were formed. The first hypothesis was that left lateralisation of speech in the frontal and temporal regions would be found. Secondly, a greater brain response in these regions for mismatched stimuli and thirdly a faster processing speed for speech stimuli. No predictions were formed about the time course of speech and non-speech processing due to the limited research in this area. This present study is highly unique in how it directly compares speech and non-speech processing in infants, without the confounds of an oddball paradigm (Sussman, Chen & Fort, 2013), using a method (ERP) with very high temporal sensitivity, and with physically matched stimuli.

In the current study, left lateralisation was only found in the frontal-central (P200 and P500 components) and temporal regions (P500 component) in the speech mismatch condition (speech followed by non-speech). This finding is highly interesting as it suggests that left lateralisation of speech has not yet developed at this stage and provides support for other studies who also did not find left lateralisation for speech overall, but greater effects in the left hemisphere for speech (Kotilahti, et al., 2010; Pang, et al., 1998). This result is suggestive that infants have a left hemispheric specialisation for speech which is in place before lateralisation effects develop. Lateralisation effects in the mismatch condition were seen in the early P200 and later P500 frontal-central components suggesting that speech was being processed at both a perceptual and cognitive level in this region, as suggested by Ceponiene et al (2002). The left temporal region only showed this effect for the P500 component, suggesting that the temporal location was involved in the cognitive evaluation of the non-speech as being different to that of the speech, and perhaps associated with the identification that these are two distinct semantic categories despite the very close physical similarity of the stimuli. Unlike the left frontal-central region, the left temporal area was not found to be differentially processing the stimuli at a perceptual level but only at cognitive level. This further suggests that temporal activity is more involved in the later interpretation of speech stimuli and not the initial sensory or perceptual differentiation of the categories. The left lateralisation of speech processing during the mismatch condition in both these regions supports the notion that infants are born with a left hemisphere superiority for processing speech (Peña et al., 2003), despite full lateralisation not being seen in response to the speech stimuli at this stage, it is suggestive that infants have a left hemisphere specialisation for speech which is in place before lateralisation effects develop. This finding provides further support for previous literature which suggests that infants are not born with a left-lateralisation of language, but that this lateralisation develops over time (Balsamo, Xu & Gaillard, 2006).

Secondly, it was hypothesised that a mismatch effect would be present when speech was presented along with non-speech, potentially in the left hemisphere as this region has been found to play an important role in language processing (Dronkers et al., 2004; Price, 2010; Hickok & Poeppel, 2007; Keller et al., 2009). A mismatch was found, but only for the speech conditions (when speech was followed by non-speech). Further to this, the mismatch effect was seen in the left temporal region in addition to the left and centre-frontal-central regions. This finding demonstrates that infants have a sophisticated neural network for speech processing, particularly as their brains are able to discriminate between the stimuli presented despite how distinctly similar the two categories of stimuli were, from a physical standpoint. Mismatch differences were found in both the P200 and P500 components in the left and centre-frontal-central region and in the P500 component in the left temporal region. The time-course of the mismatch response provides support for the earlier finding of the frontal-central areas processing speech at a perceptual stage and then cognitive stage but the temporal regions providing a cognitive input only. Additionally, this finding could potentially be linked to adult research which suggests that temporal activations are associated with lexical processes (Friederici, 2006). Therefore it is possible that the later component found in the temporal regions is an assessment of the construction and structure of the stimuli presented.

Thirdly, it was hypothesised that speech would be processed faster than non-speech in the frontal-central region as found by Dehaene-Lambertz and colleagues (2006). The current study's results did not support this finding. One possible reason for this outcome could be due to the high physical similarity between the speech and non-speech stimuli. As the stimuli are so closely matched they may be processed in the same way initially at this age and differentiations between the categories are only made at the initial perceptual stage (P200) and during the later appraisal of the stimuli at around 500ms (P500).

An advantage of the current study is that it provided a clear measure of speech versus non-speech relative to existing MMN studies. It allowed for categorical comparisons without the confound of attentional orienting mechanisms that are activated during the oddball trials of the MMN (Sussman, Chen & Fort, 2013). ERP methodologies are widely employed in infancy language studies (Dehaene-Lambertz, 2000; Dehaene-Lambertz & Baillet, 1998; Pang et al., 1998) as they allow researchers to measure automatic brain responses to stimuli allowing an insight into the neural processes involved in language processing (Kaan, 2007). Additionally as ERPs are a temporally sensitive measure (Friederici, 2006) this method provides a detailed measurement of information (in comparison to other methods such as fMRI) about the time course of brain responses in relation to speech and non-speech stimuli.

Despite the usefulness of the ERP technique in mapping the time-course of speech processing in infancy and the measurement of automatic brain responses, this EEG methodology also represents a major limitation in terms of fully identifying the neural areas involved. Due to the manner of EEG, ERPs only reflect the surface measurements of activity which is a result of activity from many different sources in the brain (Kushnerenko et al., 2002). Therefore, it is possible that activation recorded from electrodes over the frontal lobes may be a direct result of activation in another area, for example a dipole of activation with sources in the temporal lobes.

Another potential limitation of the current study is the statistical analysis which was employed. Several multiple comparisons were conducted, ANOVAs were initially performed and t-tests were then employed to test for between group differences. Due to the amount of comparisons conducted on the current data, this could open the analyses to a type one error, which is the incorrect rejection of the null hypothesis, meaning that significant results may be found where they do not exist (Field, 2013; Pallant, 2013). Typically a Bonferroni pairwise comparison is used where multiple comparisons are performed to control for type one errors (Field, 2013; Pallant, 2013). The Bonferroni raises the critical value of the statistical test according to how many tests are being carried out which reduces the likelihood of a type one error occurring (Field, 2013; Pallant, 2013). Despite this potential limitation, the current study's significant results were highly significant and also had medium or large effect sizes. This therefore suggests that the effects found were unlikely to have occurred by chance.

A further limitation of this study is in regards to participant handedness. Handedness and lateralisation for language are largely connected (Khosravizadeh & Teimournezhad, 2011). Typically, right-handed individuals will show a left lateralisation for language and right hemispheric dominance for language is more commonly found in left-handed individuals (Khosravizadeh & Teimournezhad, 2011). Despite these typical handedness and lateralisation associations, the link between handedness and lateralisation is currently unknown, not all left-handers will show a right hemispheric dominance for language and vice versa for right handed individuals (Khosravizadeh & Teimournezhad, 2011). There is much controversy revolving around the age at which children develop handedness as young children tend to show weak and inconsistent hand preferences initially (Scharoun & Bryden, 2014). However, hand preference is believed to emerge early in infancy (Scharoun & Bryden, 2014), with reaching (Marschick, Einspieler, Strohmeier, Plienegger, Garzarolli & Prechtl, 2008) and grasping behaviours (Michel, Sheu & Brymley, 2002; Michel, Tyler, Ferre & Sheu, 2006) being predictive of hand preference later in life. A review by Butterworth and Hopkins (1993) suggest that hand preference can be reliably measured from 6-months of age. In regards to the current study, participants were only 3- to 5-months old so it could be argued that the effect of handedness on language lateralisation should not influence the results. However, genetic influences are believed to contribute to handedness (Corballis, Badzakova-Trajkov & Haberling, 2012; Scharoun & Bryden, 2014), furthermore hand preferences have also been found to run in families (Annett, 1972; Corballis et al., 2012). Therefore, it is possible that the current study's results could have been influenced by the future handedness of the infant.

In regards to the limitations of the current study, several future directions have been proposed. Firstly, given the limitations of the ERP methodology in identifying sub-cortical areas responsible for scalp activations, it would be beneficial conduct a source analysis on the dataset. This would allow the ability to determine the underlying brain areas responsible for the scalp activations seen in speech processing. A secondary future direction for this study would be to use the closely matched speech and non-speech stimuli in children and adult participants. As the neural basis of typical language development is currently not fully understood within the literature (Friederici, 2006) this will enable researchers the opportunity to develop a deeper understanding of how speech processing in infancy contributes to the neural mechanisms for speech processing in later life, observing how it continues to develop through childhood. Thirdly, in regards to the role of genetics in determining handedness, a future direction for this work could be to include a measure of maternal and paternal handedness. Family handedness could then be incorporated into the analyses to control for this potential confound. A final future direction would be to include more participants as fewer infants were ultimately included in the final analysis than anticipated. The current study does, however, provide preliminary data into speech versus non-speech processing in infancy.

In summary, the results of this study provide preliminary evidence for specialisation of the left hemisphere for speech processing during infancy, as a mismatch effect was observed in electrodes over frontal central regions and temporal regions. Furthermore, the left-frontal-central region was found to have an early perceptual role followed by a later higher level cognitive role of speech processing during the mismatch condition. The activity recorded over the left-temporal region, however, was only associated with a stage of cognitive evaluation of stimuli during the mismatch condition. This suggests that both regions are specialised for speech-specific processes, but with the temporal region playing a role in the later interpretation of speech stimuli and not the initial differentiation of the categories. Despite the close physical nature of the speech and non-speech stimuli, differential infant brain responses during the speech mismatch versus match conditions strongly suggests that the infants brain automatically discriminated between the speech and non-speech categories. The findings of the current study therefore, suggest that a relatively sophisticated neural network for speech processing exists from early infancy. Future research should aim to incorporate measures of maternal and paternal handedness and to explore the sources of the underlying brain mechanisms involved in speech versus non-speech processing. With these changes in mind, it would also be beneficial to conduct the study with child and adult samples in order to provide a deeper understanding of how speech processing in infancy contributes to the development of neural mechanisms for speech processing in later life.

CHAPTER 4

SOCIAL AND NON-SOCIAL PROCESSING IN INFANCY

AND

THE EFFECT OF MOTHERS ANXIETY SYMPTOMS UPON INFANT BRAIN FUNCTIONING

4.0. RATIONALE

The previous chapter (Chapter 3, Speech and non-speech processing in infants) provided potential evidence for an early social processing system in the infant brain. Neural differences were found in three to five month old infants when listening to social and non-social stimuli. As marked differences were found for auditory social and non-social stimuli, the present chapter will move onto explore if differences are also found when infants are exposed to visual social and non-social stimuli. Methods which employ social and non-social stimuli are commonly used when obtaining measurements of resting EEG in infants (Diego, Field, Hart, Hernandez-Reif, Jones, Cullen, et al., 2002; Fox et al., 2001; Hane, Fox, Henderson & Marshall, 2008; Beaton, Schmidt, Ashbaugh, Santesso, Antony & McCabe, 2008), yet little is known about the impact of these stimuli upon infant frontal asymmetries (Greene & Zadiel, 2011). Furthermore, these resting EEGs are often used to explore the impact of emotional based disorders upon brain functioning (Beaton, Schmidt, Ashbaugh, Santesso, Antony & McCabe, 2008; Henriques & Davidson, 1991). Therefore, part one of the current chapter (4.1) created a paradigm to explore the impact of social and non-social visual stimuli upon infant brain functioning. Part two (4.2) will explore the impact of maternal anxiety traits upon infant brain functioning, as this area is currently under-researched, using the paradigm created in part one. Infant EEG data from part one of this chapter will be compared to the current levels of their mother's anxiety.

CHAPTER 4

PART ONE

4.1. SOCIAL AND NON-SOCIAL PROCESSING IN INFANCY

4.1.1. ABSTRACT

Frontal EEG asymmetries can be indicative of social behaviours in infants (Coan & Allen, 2003; Davidson, Ekman, Saron, Senulis & Friesen, 1990; Dawson, 1994; Field & Diego, 2008; LoBue, Coan, Thrasher & DeLoache, 2011; Mundy, Card & Fox, 2000). Researchers regularly collect resting state EEG from the prefrontal cortex (PFC) whilst infants experience social and non-social stimuli separately or in combination. Differences in social behaviour have been found in male and female infants (Baron-Cohen, Ring, Wheelwright, Bullmore, Brammer, Simmons, et al., 1999; Lutchmaya, Baron-Cohen & Raggatt, 2002). However, little is known about the impact of these social and non-social stimuli upon frontal EEG asymmetries (Greene & Zaidel, 2011).The aim of the current study was to explore the role of social and non-social stimuli upon infant frontal asymmetries. EEG data was collected and analysed from fifty-four 3- to 5-month old infants whilst they watched social (adults reading nursery rhymes) and non-social (colourful objects moving around the screen) videos. The initial finding of this study was that greater left frontal activation was coupled with the social condition indicating that infant brain functioning was influenced by the social stimuli. However, future work is needed to establish whether the greater left frontal activation found in the social condition is a result of the social nature of the experience per se, or a result of the infants demonstrating a positive reaction in response to the positive nature of the condition. Additionally, a novel finding of the current study was that female infants showed greater right frontal brain activation during the non-social condition than the social condition. Male infants did not show hemispheric differences for either condition. The greater right frontal activation in the non-social condition was interpreted as the female infants having

a negative response to the non-social stimuli and therefore a greater preference for the social condition. This finding is unique in that it provides neurobiological evidence for social preferences between gender in infants. Further results about the role of the orbitofrontal and dorsolateral prefrontal cortices and implications of findings are discussed within the chapter.

4.1.2. INTRODUCTION

Social cognition is the ability to respond to socially relevant information (Adolphs, 2001). It guides behavioural responses to socially relevant stimuli in terms of decision making, motivation, attention, and emotion (Adolphs, 2001). Infants have been found to possess many of the skills needed for more mature aspects of social cognition (Adolphs, 2001) such as initiating joint attention bids (Mundy, Hogan & Doehring, 1996) and understanding that actions of others are intentional (Woodward, 2009). Studying social cognition in infants has aided our understanding of early social skills but the research is still limited (Adolphs, 2001). Large gaps remain between the behavioural studies which demonstrate early cognitive skills and our understanding of the key brain areas which are implicated in adult social processing (Grossmann, Striano & Friederici, 2006). Therefore further research is needed to bridge this gap, to enable researchers to understand how typical neural social processing systems develop or whether these processing systems are in place from birth.

4.1.2.1. Prefrontal Cortex

The prefrontal cortex (PFC) has been found to have many important roles in cognition (Miller & Cohen, 2001), but it plays a particularly critical role in social (Coan & Allen, 2003; Davidson et al, 1990) and emotional (Davidson, 2004) functioning within infancy. Studies have found that early damage of the PFC leads to impaired social skills (Anderson, Bechara, Damasio, Tranel & Damasio, 1999; Raine & Yang, 2006). Anderson and colleagues (1995) found social skills in people with PFC damage were impaired even though individuals possessed basic cognitive abilities. Furthermore, individuals with early PFC damage during infancy in comparison to later damage in adulthood showed defective social and moral reasoning during social judgement tasks. These results suggest that the development of social skills begins in infancy and is highly associated with the development of the PFC. Furthermore, other modalities such as listening to speech and viewing faces are also considered to be an essential part of social experiences (Grossmann, Striano & Friederici, 2006). Different neuroimaging studies exploring these modalities in infancy have also implicated the PFC in social processing (Naoi, Minagawa-Kawai, Kobayashi, Takeuchi, Nakamura, Yamamoto, et al., 2012; Tzourio-Mazoyer, De Schonen, Crivello, Reutter, Aujard & Mazoyer, 2002). For instance, an FNIRS study in 4-to-13-month olds showed increased PFC activation in response to human speech (Naoi et al., 2012). Additionally, Tzourio-Mazoyer et al. (2002) also found increased activation in the PFC in 2-month-olds during a PET scan when they were presented with faces.

4.1.2.2. Frontal Asymmetries

Neuroimaging techniques such as EEG have provided an insight into the role of the PFC in social processing (Coan & Allen, 2003; Davidson et al, 1990; Dawson, 1994; Field & Diego, 2008; Hane, Fox, Henderson & Marshall, 2008; LoBue et al., 2011; Mundy et al., 2000). For instance, frontal EEG asymmetries show the difference in power between the right and left hemispheres and indicate trait tendencies in social behaviours. Differences in frontal EEG activation can indicate the direction of an infants' emotions (Dawson, 1994), social approach (Coan & Allen, 2003; Davidson et al, 1990; Dawson, 1994; Field & Diego, 2008; Mundy et al., 2000) and temperament (LoBue et al., 2011) which will be explored in further detail below.

4.1.2.2.1 Emotion Regulation

Research has demonstrated that the emotional environment an infant is exposed to can influence behavioural and neural processing of facial expressions. In an ERP study, Haan, Belsky, Reid, Volein and Johnson (2004) examined the potential influence of emotional experiences on infant responses to emotional expressions. Forty 7-month old infants were exposed to pictures of fearful, happy and neutral faces whilst EEG was recorded. Analysed ERPs were compared to measurements of maternal affect and infant temperament. The results revealed that infants who were rated as fearful by their mothers displayed a greater negative component over the right hemisphere in response to fearful faces. Infants who were rated as positive and who also had positive mothers also displayed a larger negative component in response to fearful faces, however, this effect was only found bilaterally. The authors interpret the neural differences as a reflection of variations in infant emotional state/temperament in addition to maternal emotional state. The results suggest that variation in emotional environment contributes to behavioural and neural differences when infants are exposed to emotional expressions.

In terms of frontal asymmetries, emotional states have been found to be associated with increased differential activation of the right and left frontal brain regions (Dawson, 1994). Emotions such as happiness and sadness are associated with increases in frontal lobe activation. Sadness is associated with greater right frontal brain activity where as happiness is associated with greater left frontal brain activity. Frontal lobe activation patterns have been found to be determined by the direction of the emotions i.e. whether an individual is displaying approach or withdrawal emotions. Various researchers have provided evidence that emotions coupled with approach towards the external environment are reflected in greater left frontal activation, and emotions associated with withdrawal, for example sadness, are accompanied by greater right frontal activation (Davidson et al., 1990; Wheeler, Davidson & Tomarken, 1993). See chapter 1 General Introduction (section 1.3.2.1.) for further information on emotional regulation.

4.1.2.2.2. Social Approach

As with emotions, social approach and exploring behaviours are characterised by greater left frontal brain activation (Davidson et al, 1990; Field & Diego, 2008). Withdrawal and fleeing behaviours from the external environment are characterised by greater right frontal brain activation (Davidson et al, 1990; Field & Diego, 2008). For instance, Hane, Fox, Henderson and Marshall (2008) explored frontal asymmetries in relation to approach and withdrawal behaviours in 779 4-month-old infants. Infants were presented with a puppet and were measured on their levels of attention towards the stimulus, the amount of positive and negative motor reactivity they displayed in addition to the number of escape behaviours demonstrated (i.e. struggling to avoid the puppet and trying to escape from the highchair). Lower infant scores indicated more withdrawal behaviours and higher scores indicated increased approach behaviours. These scores were then compared to infant EEG recordings which were obtained separately. Results revealed that infants who displayed mostly withdrawn behaviours had greater right frontal brain activation, whilst infants who displayed more approach behaviours had greater left frontal activation. These results and others from studies of frontal asymmetries are therefore suggestive of whether and individual is likely to display approach or withdrawal behaviours (Dawson, 1994; Hane et al., 2008).

4.1.2.2.3. Joint Attention

Joint attention refers to an individual's ability to coordinate attention with a social partner and is considered a major milestone of infancy (Mundy & Willoughby, 1998). Initiating joint attention can be seen as an extension of social approach as it is achieved when an individual alerts another to an object of shared focus by either eye gaze, pointing or through verbal or non-verbal communication (Mundy & Newell, 2007). In infancy, this can involve an infant directing an adult to an object through the use of eye contact and gestures. Mundy and colleagues (2000) conducted an EEG study examining initiation of joint attention in infancy and frontal EEG. Resting EEG data was collected from 37 infants prior to their completion of the revised Early Social Communication Scales (ESCS; Mundy, Hogan & Doehring, 1996), which was used as a measure of joint attention initiation in infants. As with social approach, greater left frontal activation was found when infants initiated joint attention with another individual.

4.1.2.2.4. Temperament

Frontal EEG asymmetries are also believed to be an indicator of temperament (LoBue et al., 2011). Temperament is thought to provide the basis for social and emotional development as it represents individual differences in response styles that remain relatively stable over an individual's life (Fox, et al., 2001; Rothbart & Derryberry, 1981). Infants who exhibit greater left frontal activity at rest are regarded as having easier temperaments, and are more easily soothed and calmed in comparison to infants who display greater right frontal activation (Fox et al., 2001). See chapter 1: General Introduction (section 1.3.1.1.) for more information on infant temperament.

As demonstrated, increased left frontal brain activation in infancy has been linked with predicting individual differences in social approach (Coan & Allen, 2003; Davidson et al, 1990; Dawson, 1994; Field & Diego, 2008), social attention coordination (Mundy et al., 2000), and temperament (LoBue et al., 2011). These findings are highly suggestive that frontal asymmetries are influenced by social experience. Studies investigating individual differences in frontal brain asymmetries regularly rely upon collecting resting state EEG (Coan, Schaefer & Davidson, 2006). Resting state EEG has been obtained through a variety of methods whilst infants experience social and non-social stimuli separately or in combination. For instance, infants may be entertained by a researcher (Fox et al., 2001; Hane et al., 2008) or they may watch non-social stimuli such as screen-savers on a computer or attend to a bingo ball machine (Diego, Field, Hart, Hernandez-Reif, Jones, Cullen, et al., 2002; Schmidt et al., 2008). Generally speaking these stimuli are not well defined as little is known about the impact of social and non-social experiences on frontal EEG asymmetries (Greene & Zaidel, 2011). These methods leave open the possibility that the infant's response to the social nature of the interaction is driving recorded differences in brain activation as opposed to what the researcher has aimed to measure, for example, the infants' resting brain activation. As a result, it is difficult to determine whether frontal activation patterns found within previous studies are the result of the general traits of the infant or whether the effects are driven by stimuli the infant has experienced (i.e., state) or perhaps an interaction of the two (state by trait interaction).

4.1.2.3. Gender

Despite social differences being reflected in frontal asymmetries, it is important to note that sociability is also sexually dimorphic (Connellan, Baron-Cohen, Wheelwright, Batki & Ahluwalia, 2000; Lutchmaya et al., 2002). Differences in social behaviour have been documented in males and females in infancy in terms of social interaction, social understanding, and intimacy (Baron-Cohen et al., 1999; Lutchmaya, 2002). Females are described by some as socially superior (Connellan et al., 2000; Lutchmaya et al., 2002), and have been found to show greater levels of eye contact in comparison to their male counterparts (Lutchmaya et al., 2002). For example, Lutchmaya and colleagues explored levels of eye contact with a parent in seventy 12-month-old infants. Infants were filmed for twenty minutes and were scored in terms of frequency (amount of times they looked at their parent) and duration (how long they looked at their parent). Female infants demonstrated significantly higher levels of eye contact in comparison to their male counterparts. A study by Connellan and colleagues investigated sex differences in attending to social and non-social objects with 102 neonates (Connellan et al., 2000). Participants were presented with a moving face and a moving mobile separately. Looking time for each stimulus was then calculated. Male infants looked significantly longer at the mobile than female infants, additionally females infants looked significantly longer at the face than male infants. The authors attributed the differences to female infants having a preference for faces and males having a preference for mechanical objects. In another study by Lutchmaya and Baron-Cohen (2002) a looking preference between genders was found for social and non-social stimuli. Sixty, 12-month-old infants were shown video clips of human faces (social) and cars (non-social) and the time each participant looked at the stimuli was calculated. The results revealed were similar to Connellan et al., (2000), with males showing a non-social preference in comparison to females, who displayed a social preference.

4.1.2.4. Social Processing Circuits (OFC and DLPFC)

The prefrontal cortex in general has been implicated in several aspects of social and emotional functioning, including social approach (Coan & Allen, 2003; Davidson et al, 1990; Dawson, 1994; Field & Diego, 2008; Mundy et al., 2000) and temperament (LoBue et al., 2011). Within the current neuroscience literature on frontal EEG asymmetries, most measures have been designed to reflect the dorsolateral portions of the PFC (Davidson, 2004) for instance, as previously discussed, asymmetry research on emotion regulation (Davidson et al., 1990; Wheeler et al., 1993), social approach (Davidson et al., 1990; Field & Diego, 2008) are just a few examples. However, at the same time, it has been increasingly recognised that there are actually two major social processing circuits linked to the PFC that aid social cognition (Bachevalier & Loveland, 2006). The first circuit involves the dorsolateral prefrontal cortex (DLPFC) which is interconnected with the motor, auditory, and visual cortices (Miller & Cohen, 2001; Wallis & Miller, 2003), and is believed to play a key role in emotion regulation (Golkar, Lonsdorf, Olsson, Lindstrom, Berrebi, et al., 2012). In addition, the dorsolateral region of the PFC is associated with a variety of cognitive processes and plays a more general role in representing the attentional demands of a task in terms of processing information held in working memory (Golkar et al., 2012; Wallis & Miller, 2003).

The second social processing circuit involves the orbitofrontal cortex (OFC) and is believed to be important in the monitoring of emotional states, social cognitive functions, and self-regulation of behaviour through understanding the intentions and emotional responses of others (Barbas, 1995; Brothers, 1995). The OFC is located on the ventral surface of the frontal lobes (Barbas, 1995) and is believed to be the sector of the PFC most associated directly with emotion (Hornak, Bramham, Rolls, Morris, O'Doherty, Bullock, et al., 2003). In addition, the OFC has been proposed to be important for the development of social skills (Baron-Cohen et al., 1999). Baron-Cohen et al. (1999) explored the role of different brain regions in social intelligence, an individual's ability to interpret others' behaviours in terms of mental states. Social intelligence involves predicting how others think, feel, and behave, in addition to interacting in complex social groups. Baron-Cohen et al. (1999) conducted an fMRI study which compared typical participants to individuals with high-functioning autism or Aspergers syndrome, as previous research has shown the latter groups to have deficits in social intelligence. Participants judged what a person might be feeling or thinking from the expression in their eyes. The results revealed increased activation in areas of the OFC for the non-autistic group in comparison to the autistic group when using social intelligence. Due to the autistic group having deficits in social intelligence and not showing increased activation in the OFC, the authors attributed the increased activation in the OFC in the non-autistic group to therefore be coupled with social intelligence ability.

The OFC and DLPFC have been implicated in multiple aspects of social processing (Bachevalier & Loveland, 2006; Baron-Cohen et al., 1999; Golkar et al., 2012). However, it is important to note that there have been some suggestions that activity in the OFC is consistent with asymmetry patterns in the DLPFC (Kawasaki, Kaufman, Damasio, Damasio, Granner, Bakken, et al., 2001). Further to this, similarities in behaviour and activation patterns between the OFC and DLFPC have been observed (Golkar et al., 2012). In a study by Golkar and colleagues (2012), 58 participants participated in an fMRI study and were instructed to reappraise negative and neutral pictures. This involved the participants reinterpreting the meaning of the stimuli presented to them, and their task was to neutralise the experience of the emotion elicited by the picture. Interestingly, the results revealed that the OFC was associated with the down-regulation of negative stimuli. Overall, greater right OFC activation was seen during the reappraisal of negative pictures. This finding suggests that the roles of the left and right hemispheres within the OFC and DLPFC may be similar. For example, greater right activation in the OFC is associated with the reappraisal of negative stimuli, which is consistent with greater right activation in the DLPFC for negative emotion or affect, including anger and sadness (Davidson et al., 1990; Dawson, 1992). Therefore, it is possible that greater left activation in the OFC may be coupled with positive and approach behaviours, just as it has been in the DLPFC (Davidson et al., 1990; Dawson, 1992).

4.1.2.5. Aims and hypotheses

The first aim of this study was to explore the effect of the social and non-social conditions on frontal asymmetries as little is known about the impact of social and non-social experiences in the infant brain (Greene & Zaidel, 2011). Previous methods of obtaining resting EEG have used social interactions (Fox et al., 2001; Hane, Fox, Henderson & Marshall, 2008), non-social stimuli (Diego et al., 2002; Schmidt et al., 2008) or a mixture of the two. This means that it is possible that the infant's response to the social nature of the interaction could drive differences in brain activation. It was predicted that irrespective of infant gender, greater left frontal activation would be associated with the social versus the non-social condition.

The second aim of this study was to explore social and non-social processing in frontal asymmetries between genders as differences in social behaviours have been documented between male and female infants (Baron-Cohen et al., 1999; Lutchmaya, 2002). This leaves open the possibility that gender differences in social behaviours could be reflected in frontal asymmetries. Specifically, females were predicted to exhibit greater left frontal brain activation during the social condition than for the non-social condition and males were predicted to show greater left frontal activation for the non-social condition than for the social condition.

The third hypothesis was that infants would display greater left frontal activation overall. This was predicted as infants with greater left frontal activation are generally associated as having mothers with higher levels of psychological well-being (Davidson, 2004) in comparison to infants of mothers with emotion based disorders who typically exhibit greater right frontal brain activation (Diego et al., 2006; Field & Diego, 2008; Jones, Field, & Almeida, 2009). As participants were recruited from the community (see chapter 2: General Methodology, section: 2.2.1. for further information on participant recruitment) it was assumed that mothers of infants would be considered psychologically well as all mothers were asked prior to participation if they had a current mental health disorder.

The final aim of the current study was to investigate asymmetry patterns in the OFC and DLPFC. Both of these regions of the prefrontal cortex have been found to play key roles in social and emotional functioning. However, comparisons of activation have never been directly examined in an EEG study, because the majority of the literature on prefrontal asymmetries has focused specifically on the dorsolateral region (Davidson, 2004). It was hypothesised that no significant interactions would be found, in terms of greater activation for a particular region (orbitofrontal or dorsolateral) and a particular condition (social or non-social). This was hypothesised as there have been suggestions that asymmetry activity in the OFC is consistent with asymmetry patterns in the DLPFC (Kawasaki et al., 2001), with both regions having similar hemispheric roles (Golkar et al., 2012).

4.1.3. METHOD

4.1.3.1. Participants

Participants were infants aged between three and five months old who had been recruited via the Infant and Child Laboratory at the University of Birmingham (see chapter 2: General methodology, section: 2.2.1. for further detail on recruitment). Parents provided written consent for their child to participate after having the study explained to them by the experimenter. Infants received a small toy for taking part, and parents received £10 to cover expenses for travelling to the University-based laboratory.

EEG data was collected from seventy-two participants whilst watching videos of social and non-social stimuli. Prior to statistical analysis eighteen infants were excluded for having artifact-free EEG data that was less than one minute in either social or non-social condition. Both conditions yielded a high amount of usable EEG data (Social: 1:57 minutes, SD: 42; Non-Social: 2:16 minutes, SD: 52). One minute of artefact free EEG data was chosen as a cut-off point due to the considerable variability in the amount of EEG data used across studies measuring resting EEG in infants (Thibodeau, Jorgensen & Sangmoon, 2006). Furthermore, longer recording times are believed to increase the stability and reliability of the EEG measurement in addition to providing a more valid estimate of resting frontal asymmetry (Thibodeau et al., 2006).

As none of the women recruited via the Infant and Child Laboratory had a current mental illness, no participants were excluded on the basis of this. Thus, the final sample included fifty-four infants (30 female), with a mean age of 140 days (SD: 26.36), each of whom provided both Social and Non-Social data.

4.1.3.2. Questionnaires

Prior to participating, all mothers completed a demographic questionnaire. This questionnaire provide detailed information about the sample in terms of age of infant, ethnicity, occupation and level of education of mothers, in addition to asking if mothers had a current mental health disorder (see appendix item 1).

For information on the methods used in this chapter please refer to Chapter 2 (Stimuli: section 2.4.1.; Procedure: section 2.4.2.; EEG Recording: section 2.4.3.; Data Analysis: section 2.4.4. and Frontal EEG asymmetry calculation: section 2.4.4.1.)

4.1.3.3. Electrodes

4.1.3.3.1. Dorsolateral Prefrontal Cortex

Six left (see figure 4.1.1.) and six right (see figure 4.1.2.) frontal electrodes over the frontal scalp regions were selected for the DLPFC analysis (F3, F4) in the alpha band (6-9Hz). These electrodes were chosen as previous literature exploring frontal asymmetries, which mostly reflect the DLPFC (Davidson, 2004), use either single electrodes on F3 and F4 sites, or a group of electrodes around the F3 and F4 sites (Coan et al., 2006; Fox et al., 2001; Hane et al., 2008; Schmidt et al., 2009). F3 and F4 sites and surrounding electrodes were selected to allow a representative measurement of the left and right DLPFC as opposed to relying upon a single electrode measurement.

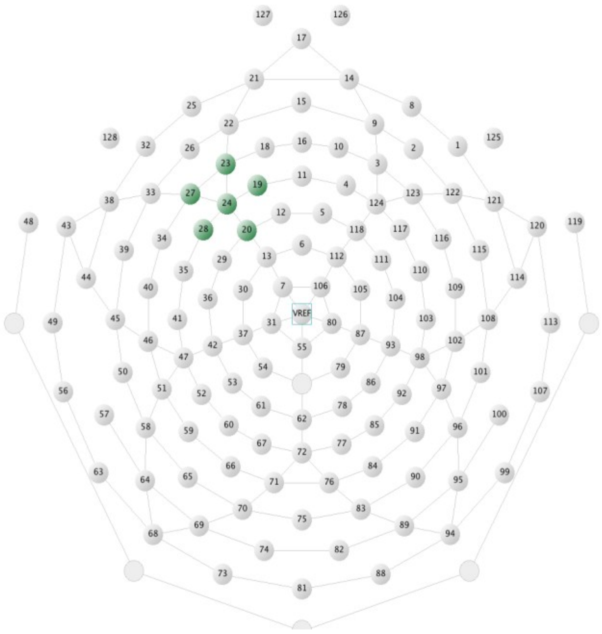

Figure 4.1.1. Left Frontal (F3)

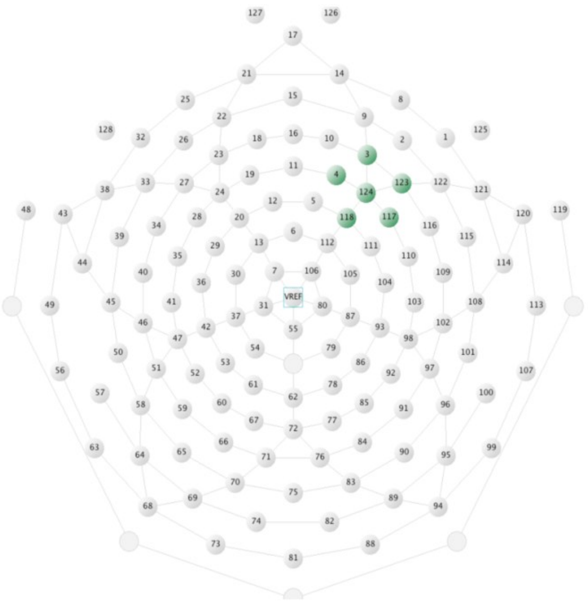

Figure 4.1.2. Right Frontal (F4)

4.1.3.3.2. Orbitofrontal Prefrontal Cortex

Six left (see figure 4.1.3.) and six right (see figure 4.1.4.) anterior frontal electrodes over the frontal scalp regions were selected for the orbitofrontal analysis in the alpha band (6-9Hz) as the OFC is positioned at the anterior part of the PFC (Barbas, 1995).

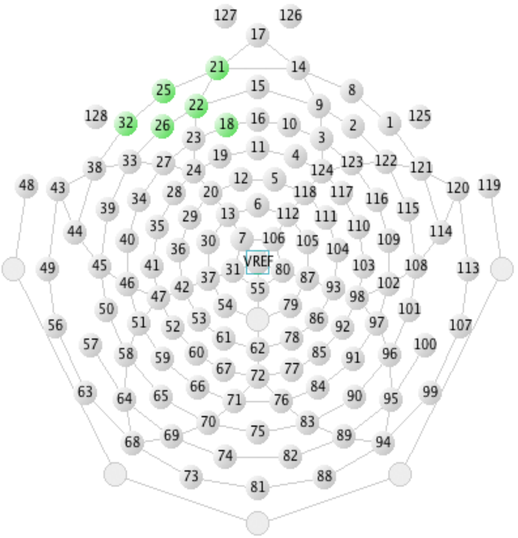

Figure 4.1.3. Left Orbitofrontal

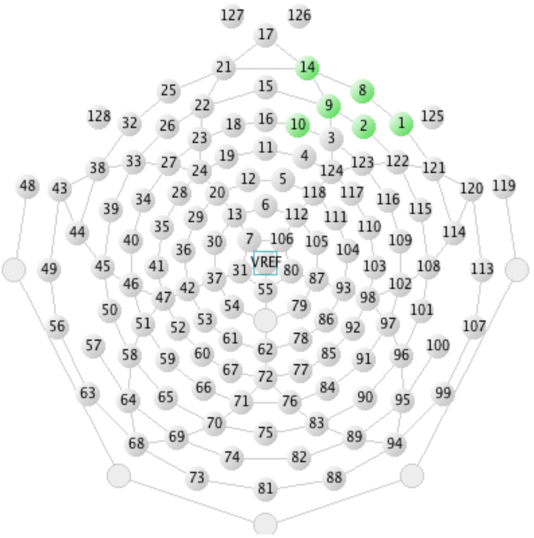

Figure 4.1.4. Right Orbitofrontal

4.1.4. RESULTS

4.1.4.1. Test of Normality

A Shapiro-Wilk test of normality was performed on the dataset for all of the groups included in the analysis. All groups returned non-significant results (see table 4.1.1.), indicating the data were normally distributed. Parametric tests were therefore performed.

Table 4.1.1

Shapiro-Wilk p-values for the OFC and DLFC data for each condition and hemisphere by gender.

	OFC		**DLPFC**	
Hemisphere by condition	**Male**	**Female**	**Male**	**Female**
Left Social	0.395	0.140	0.383	0.482
Right Social	0.107	0.486	0.161	0.763
Left Non-Social	0.463	0.137	0.202	0.947
Right Non-Social	0.77	0.241	0.824	0.633

4.1.4.2. 4-Way mixed ANOVA

In order to determine the effects of social and non-social stimuli upon frontal EEG asymmetry, a 4-way mixed analysis of variance (Split-Plot ANOVA) was performed in the 6-9Hz alpha band. Gender (male, female) was included as a between-subjects factor and region (dorsolateral, orbitofrontal), hemisphere (left, right) and condition (social, non-social) were included as within-subjects factors.

The mixed ANOVA revealed a significant main effect of region (F (1, 52) = 43.257, $p<0.001$, $n^2=0.454$; mean PSD: OFC = 0.654, DLFC = 0.433). A significantly lower PSD value was found for the dorsolateral cortex in comparison to the orbitofrontal cortex, indicating greater brain activity was occurring in the dorsolateral cortex overall (see figure 4.1.5.).

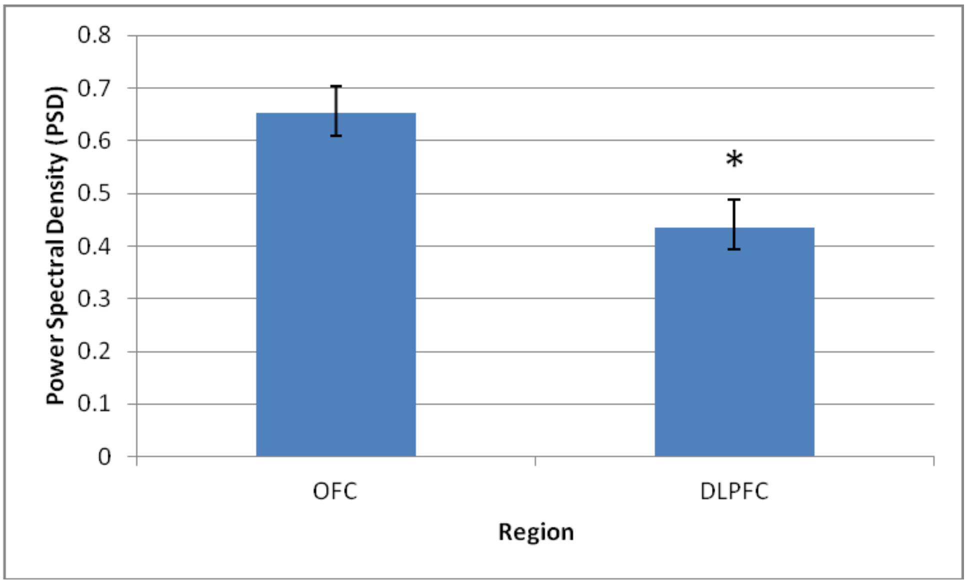

Figure 4.1.5. PSD values for the OFC and DLPFC. Error bars represent the standard error of the means. DLPFC showed significantly greater activation than the OFC ($p<0.001$).

Note: an inverse relationship exists between PSD and activation, therefore a lower PSD reflects greater activation.

A significant main effect of hemisphere was also found (F (1, 52) = 17.066, $p<0.001$, $n^2=0.247$). The left hemisphere was found to have a lower PSD value and, therefore, greater brain activation in comparison to the right hemisphere (see figure 4.1.6.).

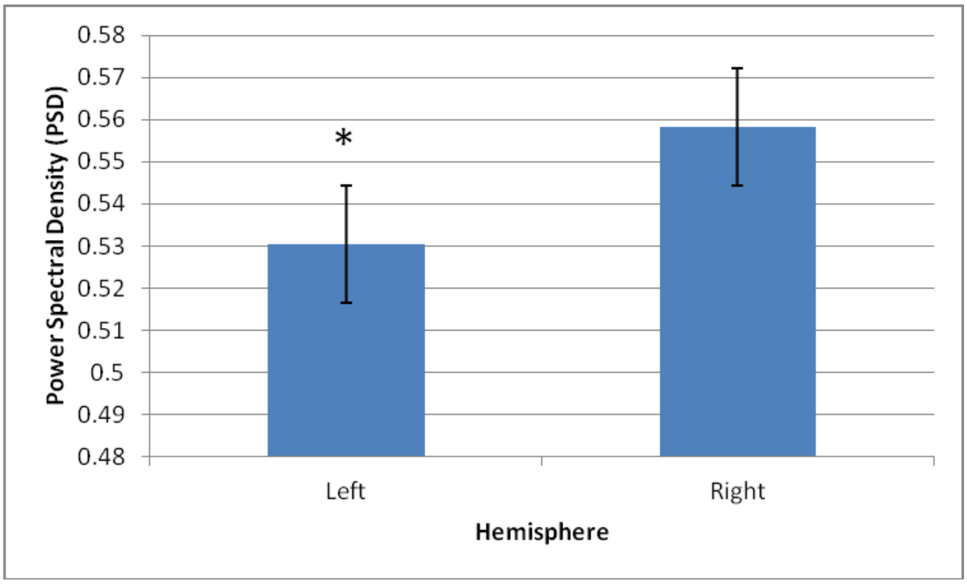

Figure 4.1.6. PSD values for the left and right hemispheres. Error bars represent the standard error of the means. The left hemisphere showed significantly greater activation than the right ($p<0.001$). Note: an inverse relationship exists between PSD and activation, therefore a lower PSD reflects greater activation.

The analysis did not reveal a significant main effect of condition (F (1, 52) = 0.910, p = 0.345, n^2=0.17) or gender (F (1, 52) = 0.014, p = 0.905, n^2=0.000), or for the interaction of these two factors (F (1, 52) = 0.523, p = 0.473, n^2=0.010) (see table 4.1.2.).

A significant interaction was found for hemisphere and condition (F (1, 52) = 5.372, $p<0.05$, n^2=0.094). Paired samples t-tests revealed significantly greater left brain activation for the social condition (t(53) = -4.112, p=0.000) as shown in figure 4.1.7. EEG power did not significantly differ for left and right hemispheres for the non-social condition (t(53) = -0.775, p=0.442) (see table 4.1.2.).

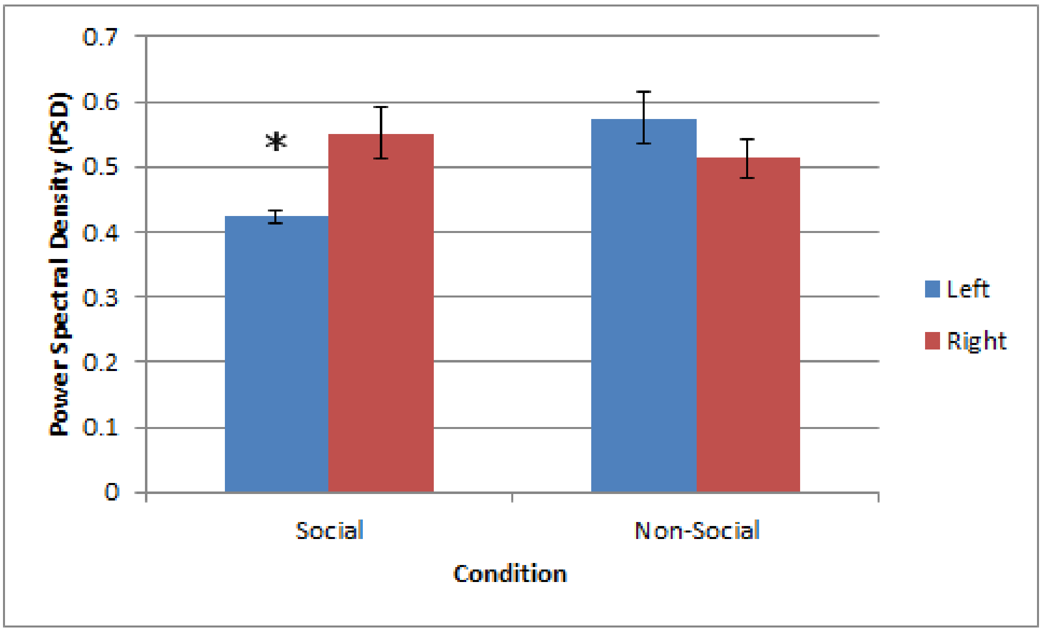

Figure 4.1.7. PSD values for significant interaction of hemisphere by condition. Error bars represent the standard error of the means. Significantly greater left brain activation is shown in the social condition. Note: * $p<0.05$.

The mixed ANOVA did not reveal significant interactions for region and gender (F (1, 52) = 1.238, p = 0.271, n^2=0.023) or hemisphere and gender (F (1, 52) = 2.944, p = 0.092, n^2=0.054). This indicates that relative left and right DLPFC and OFC EEG activity did not differ for females and males. Similarly, no significant interactions were found for hemisphere and region (F (1, 52) = 2.294, p = 0.136, n^2=0.042) or region and condition (F (1, 52) = 0.383, p = 0.538, n^2=0.007). This result indicates that left and right EEG power did not differ between the OFC and DLPFC. Finally, OFC and DLPFC EEG activity did not significantly differ for the social versus non-social conditions (see Table 4.1.2.).

The analysis did not reveal a significant interaction for region, hemisphere, and condition (F (1, 52) = 0.573, p = 0.452, n^2=0.011). EEG power did not significantly differ for DLPFC and OFC based on hemisphere and whether the infants were watching social or non-social videos. Additionally, hemisphere, condition and gender (F (1, 52) = 0.002, p = 0.969, n^2=0.000), region, condition and gender (F (1, 52) = 0.254, p = 0.617, n^2=0.005) and region, hemisphere, and gender (F (1, 52) = 0.048, p = 0.828, n^2=0.001) did not significantly interact. These results indicate that EEG activity did not significantly differ for males and females for the left and right hemispheres in either condition. Activation in the DLPFC and OFC was not significantly different for each condition for males and females. Furthermore, activation in the DLPFC and OFC did not significantly change dependent upon hemisphere for males versus females (see Table 4.1.2.).

The mixed ANOVA revealed a significant 4-way interaction for region, hemisphere, condition, and gender (F (1, 52) = 8.458, p = 0.005, n^2=0.140). To understand this interaction, results were broken down into region (OFC, DLPFC) and two further mixed ANOVAS were performed with hemisphere (left, right) and condition (social, non-social) as within-subjects factors and gender (male, female) as a between-subjects factor.

4.1.4.3. Orbitofrontal mixed ANOVA

The analysis revealed a significant main effect of hemisphere (F (1, 52) = 15.934, $p<0.001$, $n^2=0.235$). Greater left brain activation was found overall in the OFC as shown in Figure 4.1.8.

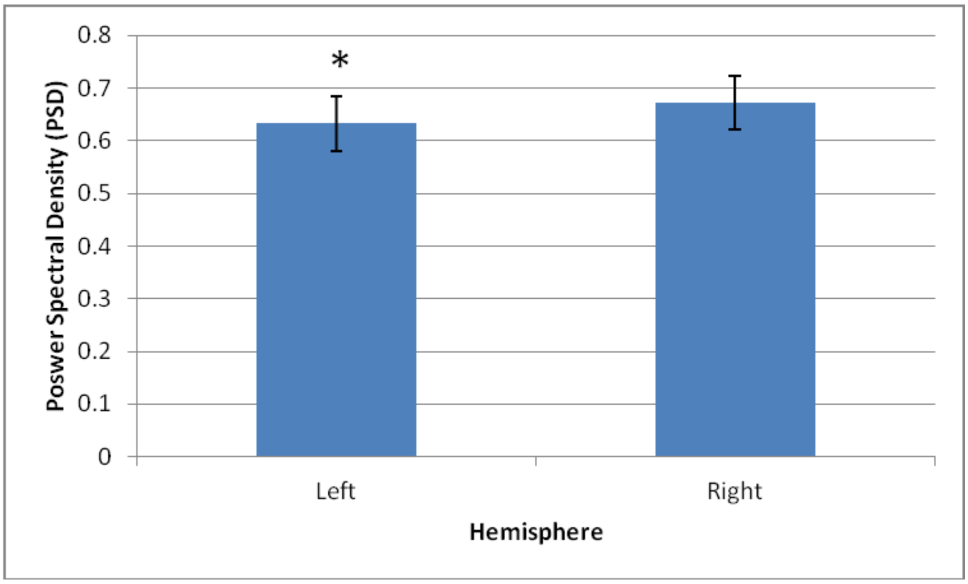

Figure 4.1.8. PSD values for left and right hemispheres in the OFC. Error bars represent the standard error of the means (overlapping error bars do not affect significance levels; see Lanzote, 2005). Greater left activation is shown in the social condition. Significantly greater left activation is shown here. Note: * $p<0.001$.

No significant main effects of condition (F (1, 52) = 1.230, p = 0.273, n²=0.023) or gender (F (1, 52) = 0.115, p = 0.736, n²=0.000) were found. Therefore, brain activation did not significantly differ in either condition or for males or females. Significant interactions were not discovered for hemisphere and gender (F (1, 52) = 1.103, p = 0.299, n²=0.021) or condition and gender (F (1, 52) = 0.735, p = 0.395, n²=0.014). This meant that left and right activation was not significantly different for males or females and activation for males and females did not differ depending on the condition (see Table 4.1.2.).

A marginally significant interaction was found for hemisphere and condition (F (1, 52) = 3.941, p =0.052, n²=0.070). Paired samples t-tests revealed significantly greater left brain activation for the social condition (t (53) = -3.541, p = 0.001) as shown in Figure 4.1.9. EEG power did not significantly differ for left and right hemispheres for the non-social condition (t (53) = -1.072, p = 0.288).

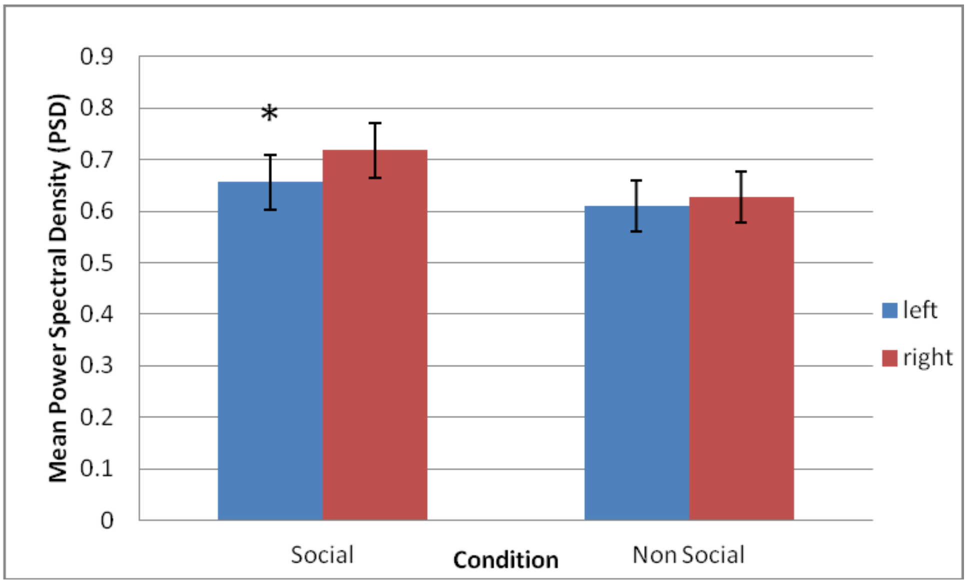

Figure 4.1.9. PSD values for a marginally significant interaction of hemisphere by condition. Error bars represent the standard error of the means. Greater left activation is shown in the social condition. Note: * p=0.052.

The ANOVA did not reveal a significant 3-way interaction for hemisphere, condition and gender (F (1, 52) = 2.660, p = 0.109, n^2=0.049). Therefore, left and right brain activation did not significantly differ in either condition and was not affected by the gender of the infant.

4.1.4.4. Dorsolateral mixed ANOVA

The analysis did not reveal a significant main effect of hemisphere (F (1, 52) = 3.251, p = 0.077, n^2=0.059), condition (F (1, 52) = 0.277, p = 0.601, n^2=0.005), or gender (F (1, 52) = 0.456, p = 0.503, n^2=0.009). Therefore, brain activation did not significantly differ in the left or right hemispheres, in either condition or for males or females. Significant interactions were not found for hemisphere and gender (F (1, 52) = 1.827, p = 0.182, n^2=0.034), condition and gender (F (1, 52) = 0.146, p = 0.704, n^2=0.003) or hemisphere and condition (F (1, 52) = 2.297, p = 0.136, n^2=0.042). This meant that left and right activation was not significantly different for males or females and activation for males and females did not differ depending on the condition. Additionally, left and right brain activation did not significantly differ for the social and non-social condition (see Table 4.1.2.).

The mixed ANOVA revealed a significant 3-way interaction for hemisphere, condition and gender (F (1, 52) = 0.456, p = 0.027, $n^2=0.090$). To interpret the dorsolateral interaction, two repeated measures ANOVAs were performed. The first, a 2 (hemisphere: left, right) by 2 (condition: social, non-social) for males. The second, a 2 (hemisphere: left, right) by 2 (condition: social, non-social) for females.

4.1.4.5. 2-Way ANOVA for males

The repeated measures ANOVA did not reveal a main effect of hemisphere (F (1, 23) = 3.997, p = 0.058, $n^2=0.148$) or condition (F (1, 23) = 0.009, p = 0.927, $n^2=0.000$) or for the interaction of these two factors (F (1, 23) = 0.246, p = 0.625, $n^2=0.011$). Therefore, males did not have significantly greater left or right brain activation, or significantly different activation in the social or the non-social conditions. Furthermore, greater left or right activation was not coupled with a specific condition for the males (see Table 4.1.2.).

4.1.4.6. 2-Way ANOVA for females

The analysis did not reveal a main effect of hemisphere (F (1, 29) = 0.127, p = 0.724, $n^2=0.004$) or condition (F (1, 29) = 0.509, p = 0.481, $n^2=0.017$). These results show that females did not have significantly greater left or right brain activation, or significantly different activation in the social or the non-social conditions (see Table 4.2.). However, the interaction of these two factors was significant (F (1, 29) = 8.435, p = 0.007, $n^2=0.225$) as shown in figure 4.1.10. Paired samples t-tests revealed significantly greater right brain activation for the non-social condition (t (29) = 2.094, p = 0.045). Left and right EEG power did not significantly differ for the social condition (t (29) = -1.982, p= 0.057).

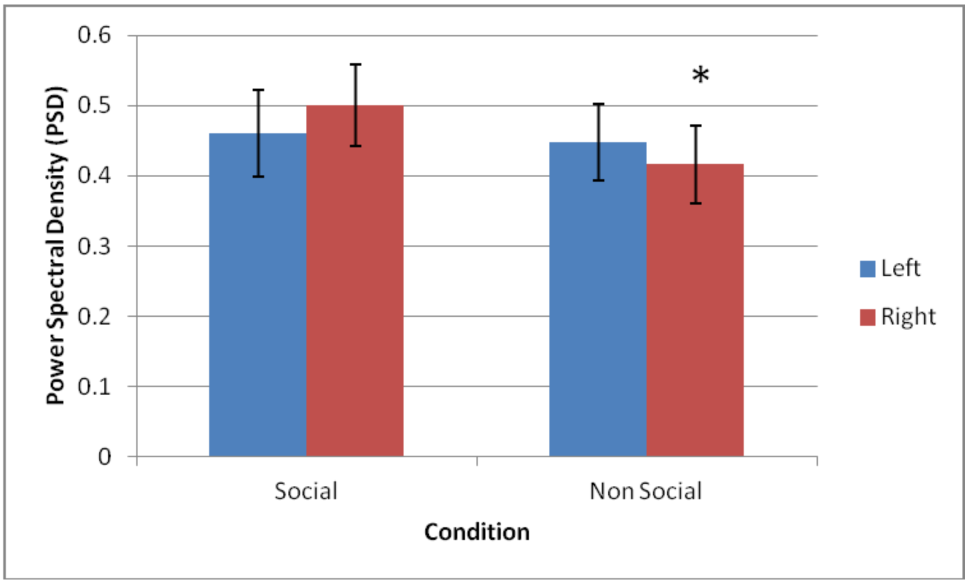

Figure 4.1.10. PSD values for significant interaction of hemisphere by condition for females. Error bars represent the standard error of the means. Significantly greater right brain activation is shown in the non-social condition. Note: * $p<0.05$.

4.1.4.7. 2-Way ANOVA for non-social condition

A final 2 (gender: male vs female) by 2 (hemisphere: left vs right) repeated measures ANOVA was performed on the non-social condition. This was to ensure the region, hemisphere, condition and gender interaction initially found related to greater right brain activation in the non-social condition only for females in the dorsolateral region. No significant main effect of gender (F (1, 23) = 0.689, p = 0.415, n^2=0.029) or hemisphere (F (1, 23) = 0.741, p = 0.741, n^2=0.005) was found (see Table 4.1.2.). The repeated measures ANOVA did reveal a significant interaction between gender and hemisphere (F (1, 23) = 4.353, p<0.05, n^2= 0.159) as shown in Figure 4.1.11. Paired t-tests confirmed that females had significantly greater right brain activation (t (29) = 2.094, p = 0.045) in comparison to no significant difference between hemisphere and condition for the males (t (23) = -1.665, p = 0.109).

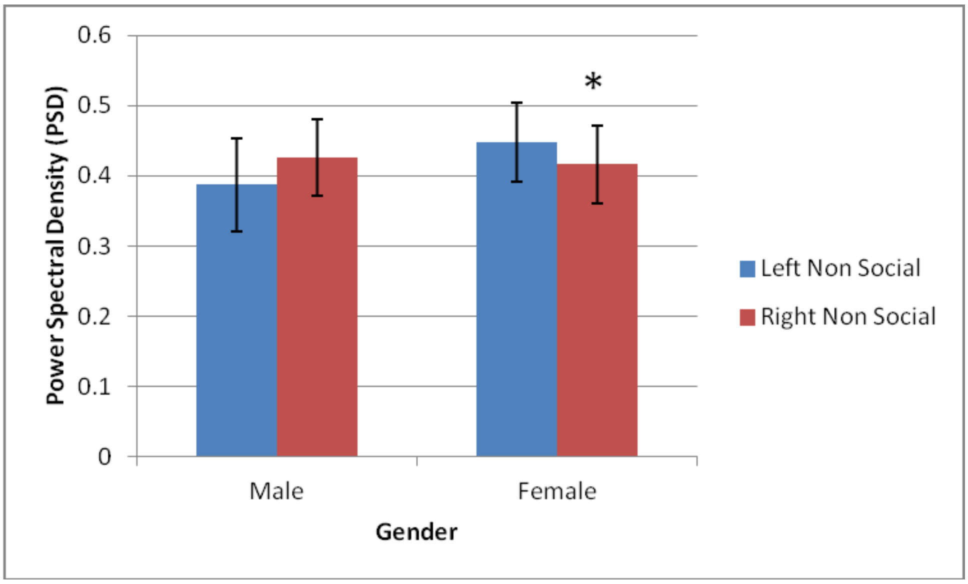

Figure 4.1.11. PSD values for significant interaction of gender by hemisphere in the non-social condition. Error bars represent the standard error of the means. Greater right frontal activation is seen in females in the non-social condition. Note: * p<0.05.

Table 4.1.2.

Mean PSDs and Standard Deviations (SD) for OFC, DLPFC and combined regions by hemisphere, condition and hemisphere by condition

	Region																	
	OFC and DLPFC						**OFC**						**DLPFC**					
	Male	***SD***	**Female**	***SD***	**Both**	***SD***	**Male**	***SD***	**Female**	***SD***	**Both**	***SD***	**Male**	***SD***	**Female**	***SD***	**Both**	***SD***
Hemisphere																		
Left	.519	*0.38*	.539	*0.31*	.529	*0.23*	0.64	*0.43*	.625	*0.31*	.634	*0.36*	.394	*0.34*	.454	*0.31*	.424	*0.34*
Right	0.56	*0.38*	.557	*0.31*	.558	*0.30*	.694	*0.46*	.655	*0.31*	.674	*0.40*	.426	*0.30*	.459	*0.31*	.442	*0.33*
Condition																		
Social	.545	*0.40*	.588	*0.32*	.567	*0.22*	.679	*0.46*	.695	*0.32*	.686	*0.40*	.414	*0.34*	.481	*0.32*	.481	*0.45*
Non-Social	.534	*0.36*	.508	*0.29*	.521	*0.14*	.662	*0.43*	.584	*0.29*	.623	*0.37*	.407	*0.30*	.432	*0.30*	.419	*0.22*
Hemisphere by Condition																		
Left Non-social	.523	*0.37*	.509	*0.33*	.591	*0.33*	.659	*0.42*	.572	*0.29*	.611	*0.35*	.387	*0.32*	.447	*0.29*	.421	*0.13*
Right Non-social	.545	*0.35*	.506	*0.31*	.526	*0.29*	.664	*0.43*	.597	*0.29*	.627	*0.38*	.426	*0.27*	.416	*0.30*	.421	*0.31*
Left Social	.515	*0.40*	.569	*0.29*	.542	*0.12*	.628	*0.44*	.678	*0.33*	.656	*0.37*	.402	*0.35*	.461	*0.33*	.434	*0.55*
Right Social	.575	*0.41*	.607	*0.30*	.591	*0.32*	.724	*0.48*	.713	*0.32*	.718	*0.42*	.426	*0.33*	.501	*0.31*	.468	*0.34*

4.1.5. DISCUSSION

The PFC has been found to play a particularly critical role in social functioning within infancy (Coan & Allen, 2003; Davidson et al, 1990). However, little is known about the impact of social and non-social experiences on frontal EEG asymmetries (Greene & Zaidel, 2011). The main focus of the current study was to investigate the role of social versus non-social stimuli upon frontal EEG asymmetries in infancy.

The main finding of the study was that females had significantly greater right frontal brain activation for the non-social condition than the social condition. This result is highly unlikely to be the result of a sampling issue due the number of participants included from each gender. Firstly, a large number of males and females were included in the analysis, and secondly, both gender groups were closely matched in number (Males: 24; Females: 30). Previous research has shown that greater right frontal activation is coupled with negative affect and withdrawal behaviours (Davidson et al., 1990). Therefore, this result is suggestive that, relative to the male infants, the female infants did not enjoy the non-social condition and consequently were showing a withdrawn/negative reaction to it. On the other hand, the male infants did not exhibit approach or avoidance-related frontal EEG asymmetry patterns during the observation of social or non-social stimuli, indicating they did not have a preference or a dislike for either condition. Although it was hypothesised that gender differences would exist, the prediction that females would show greater left frontal activation for the social condition and males greater left frontal activation for the non-social condition was not found. However, the current results still provide support for previous studies which have found females to have a preference for social stimuli (Connellan et al., 2000; Lutchmaya & Baron-Cohen, 2002; Lutchmaya, Baron-Cohen & Raggatt, 2002). As females showed a significant negative and withdrawn brain response to the non-social condition, it is highly likely that this response would be reflected in their behaviour for this condition. Therefore, this is indicative that females would have a behavioural preference for the social condition over the non-social condition. In addition, as the males did not show a difference in brain functioning for either condition this would mean they are not displaying a withdrawn or negative behavioural reaction to this condition. It is therefore possible that this would appear as the males having a non-social preference when compared to the female group as they would not be showing an avoidant reaction where the females would. This finding provides a unique insight into gender differences and early infant preferences within social and non-social processing, as only females were found to show avoidant brain activation towards non-social stimuli. Therefore this is a novel result which has provided evidence on a neurobiological level that helps to explain the body of research which has shown female behavioural preferences towards social stimuli (Connellan et al., 2000; Lutchmaya, Baron-Cohen & Raggatt, 2002).

The general effect of social and non-social stimuli upon frontal asymmetries was explored next. As predicted, greater left frontal activation was found for the social condition, indicating that the social nature of the stimuli influenced infant brain activation. This finding has great implications for previous research which has relied upon social measures as a method for collecting resting state EEG data from infants (Fox et al., 2001; Hane, Fox, Henderson & Marshall, 2008). For instance, it is possible that findings in these studies may not reflect what the authors intended to measure. Infant brain functioning may have been affected by the social nature of the resting EEG condition. Furthermore, the social condition may have elicited an approach/positive brain response in infants as it involved people reading nursery rhymes in a positive, upbeat manner. Previous research (Dawson et al., 1992) has found the frontal lobe to play an important role in infant emotion regulation, with different aspects of emotions being associated with different patterns of frontal EEG activity in infants. Positive emotions such as happiness are associated with greater left frontal activation and have been elicited in response to infants watching positive stimuli, for example, happy people (Davidson et al., 1990). It is therefore possible that the infants preferred the social condition due to the generically positive nature of the stimuli, therefore eliciting a positive/approach response from infants which was then reflected in their brain functioning.

The third finding revealed significantly greater left frontal activation in infants overall, as hypothesised. The sample of infants who participated were recruited from the community and did not have mothers with a current mental health problem, as confirmed by the results of the demographic questionnaires. This result was interpreted as the included sample of infants having mothers who are psychologically well, reflecting previous study findings which state that maternal psychological-wellbeing is associated with greater left frontal brain functioning in their infants (Davidson, 2004).

The final aim of the current study was to investigate the role of the OFC and DLPFC in social processing. A main effect of region was discovered, the DLPFC showed greater activation during the study than the OFC. One possible explanation for this result could be, as several authors have suggested (Golkar et al., 2012; Wallis & Miller, 2003), that the DLPFC plays a general role in emotion regulation and working memory. The observed greater activation could be a result of the region representing the attentional demands of the task and processing the information held within the infants' working memory. Additionally, as predicted, no significant interactions were found between region (DLPFC and OFC), hemisphere (left and right) or condition (social and non-social). Despite the fact that two distinct social circuits have been recognised for aiding social cognition (Bachevalier & Loveland, 2006), the current study suggests that the DLPFC and OFC are showing similar patterns of activity. This finding provides support for evidence from previous studies which suggest that the OFC displays a pattern of activation similar to that of the DLPFC during aspects of social processing (Golkar, 2012; Kawasaki et al., 2001).

It has been well established within the literature that prefrontal asymmetry EEG measures reflect trait-like variations in personality ((Davidson et al., 1990; Fox & Davidson, 1987; Wheeler, Davidson & Tomarken, 1993). However, the PFC is part of a complicated circuitry which involves other cortical and subcortical structures (Davidson, 2004). Due to the EEG methodology employed in the current study, measurements of scalped based activity were recorded which do not directly reflect activity in other parts of this circuitry. This is a common limitation which is shared with many studies within the frontal asymmetry literature (Davidson, 2004; Kushnerko, et al., 2002). Despite this being a common limitation, this means that there is a gap within the current literature regarding the roles played by the subcortical structures in relation to affective processes. fMRI studies have attempted to explore the roles of this underlying circuitry (Davidson & Irwin, 1999; Wager et al., 2003). However, fMRI techniques also have their limitations, and as a result conclusions related to activity levels in this circuitry cannot be made (Wang et al., 2003).Source localisation can be employed in conjunction with EEG methods to provide information on the sub-cortical sources of scalp-recorded signals (Davidson, 2004). A future direction for this study would be to conduct a source location analysis, this would provide further detail on frontal-asymmetries by exploring the roles of the sub-cortical structures which are implicated in the PFC circuitry.

A further limitation relating to measurements of cortical and sub-cortical structures is the issue of detecting activation in the OFC. In the current study, the most anterior EEG electrodes were chosen to represent the OFC as the OFC is positioned at the front of the PFC

(Barbas, 1995). However, the structure and positioning of the OFC means that a large portion of this region is sub-cortical (Barbas, 1995). As EEG reflects surface measurements of electrical activation across the scalp, neurophysiological studies of the OFC region are difficult to perform and normally rely upon invasive measures with animal populations (Davidson, 2004). Therefore, the current studies measurements of the OFC may not have been completely representative due to the methodological limitations. However, as previously discussed, if source localisations techniques are adopted in future studies, a more accurate and reliable measure of the OFC could be obtained.

A third limitation of the current study was that the social stimuli were highly unique in comparison to the non-social stimuli as they contained human movement and voices. This made the social condition virtually impossible to match to the non-social condition. Instead, the non-social stimuli used are at best a comparison baseline condition as the social condition was positive and engaging for infants in comparison to a neutral non-social condition. This therefore leaves open the possibility that the positive, engaging nature of the social condition could be eliciting a positive response and in turn greater left frontal activation in the infants as opposed to the social nature of the condition itself. A future direction for this study would be to investigate the effect of social stimuli on frontal resting asymmetries. This would include involving further social conditions whereby nursery rhymes are read with flat (neutral) affect, negative affect and again with positive affect as well as the inclusion of a non-social condition again as a baseline measure. This would allow for the investigation of whether the emotion of the social condition is driving infant brain functioning or whether it is the nature of the social condition in general which is driving the effect.

A further potential limitation of the current study, as discussed in the previous chapter, is the statistical analysis which was employed. As before, several multiple comparisons were conducted, ANOVAs were initially performed and t-tests were then employed to test for between group differences. Due to the amount comparisons conducted on the current data, this could open the analyses to a type one, family wise error (Field, 2013; Pallant, 2013). Typically a Bonferroni pairwise comparison is used where multiple comparisons are performed to control for type one errors (Field, 2013; Pallant, 2013), however t-tests were employed in the current study unadjusted for multiple comparisons. Despite this potential limitation, the current study's significant results were highly significant and also had medium or large effect sizes. This therefore suggests that the effects found were unlikely to have occurred by chance.

In summary, the current study revealed a novel finding of female infants showing greater right frontal brain activation during the non-social condition in comparison to the social condition. This finding indirectly provides support for previous research, which has found female infants to have a preference for social stimuli. Greater right frontal activation in females for the non-social condition was interpreted on a behavioural level, that females would display a negative behavioural response to the non-social stimuli and therefore would appear to have a greater behavioural preference for the social condition. This finding is therefore unique in the sense that it provides neurobiological evidence for early social preferences in female infants. Secondly, the findings also revealed that infant brain functioning was influenced by the social nature of the stimuli in the social condition, as greater left frontal activation was found overall for this condition. This result therefore has implications for previous studies, as it suggests that previous results may be biased by the social nature of the interaction the infant has experienced. However, future work is needed to establish whether the greater left frontal activation found in the social condition was a result of the social experience or a result of the infants eliciting a positive reaction in response to the condition. Additionally, infants showed greater left frontal brain activation overall which was interpreted as a reflection of higher levels of psychological well-being in the mothers of infants who participated (Davidson, 2004). The final finding of the current study was the DLPFC having greater overall brain activation in comparison to the OFC. Greater activation was interpreted as the DLPFC representing the attentional demands of the current study and the processing of the information held within the infants' working memory. Furthermore, despite the DLPFC having greater activation overall, as no interactions between hemisphere and condition were found for these hemispheres, this finding suggests that the OFC displays a pattern of activation similar to that of the DLPFC.

CHAPTER 4

PART TWO

4.2. THE EFFECT OF MOTHERS ANXIETY SYMPTOMS UPON INFANT BRAIN FUNCTIONING

4.2.1. ABSTRACT

Anxiety disorders affect a large number of the worldwide population and cause significant distress and difficulties for affected individuals on a daily basis (Barlow, 2002). Individuals with anxiety disorders show greater right frontal brain activation which is coupled with withdrawn behaviours (Beaton, Schmidt, Ashbaugh, Santesso, Antony & McCabe, 2008; Henriques & Davidson, 1991). Similarly, individuals with depression and their infants also show greater right frontal activation (Beaton et al., 2008; Dawson, Frey, Panagiotides, Osterling, & Hessi, 1997; Henriques & Davidson, 1991) but frontal activation in infants of anxious mothers has not been explored. The main aim of this study was to explore the effect of maternal anxiety symptoms upon infant brain functioning. EEG data was analysed from fifty-two 3- to 5-month old infants whilst they watched social (adults reading nursery rhymes) and non-social (colourful objects moving around the screen) videos in addition to their mothers completing the Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983) to indicate current levels of anxiety. The current study did not find mothers' trait anxiety to predict infant frontal EEG asymmetry profiles. Additionally, anxiety symptoms did not predict frontal EEG asymmetry when age and gender of the infants were included as potential modifying factors. This finding is useful in providing preliminary evidence to suggest that normal to moderate levels of anxiety symptoms within a typical community sample do not significantly or negatively affect infant brain functioning. Future work is needed in order to more fully and directly explore the effect of maternal anxiety on infant brain functioning. This would involve increasing the sample size and including an enriched sample of mothers who meet criteria for a clinical diagnosis of an anxiety disorder.

4.2.2. INTRODUCTION

Anxiety disorders affect a large number of the worldwide population and cause significant distress and difficulties for affected individuals on a daily basis (Barlow, 2002). There are a range of anxiety disorders, including Generalised Anxiety Disorder (GAD) which is excessive anxiety or worry about general occurrences in everyday life; Social Phobia, excessive anxiety associated with public embarrassment; Post Traumatic Stress Disorder (PTSD), feelings of anxiety revolving around a past traumatic event; Panic Disorder, panic attacks from excessive anxiety; and Obsessive Compulsive Disorder (OCD), compulsions and obsessions which dramatically affect every day functioning for the individual (American Psychiatric Association, 2013). Anxiety disorders are estimated to affect approximately 18.1% of the general population (Kessler, Chiu, Demler, Merikangas & Walters, 2005) and are increasingly common amongst women of child bearing age (Kessler, Keller, & Wittchen, 2001).Anxiety disorders increase disturbances in mother-infant interactions and development (Stein, Craske, Lehtonen, Harvey, Savage-McGlynn, Davies, et al., 2012).

4.2.2.1. Maternal Anxiety

In most studies mothers with an anxiety diagnosis have been described as intrusive, overprotective, and controlling (Kaitz & Maytal, 2005). Anxious mothers can be unresponsive and sad, displaying withdrawn interaction styles with their infant (Weinberg & Tronick, 1998). Studies have found relationships between the level of mothers' anxiety symptoms and deficits in maternal behaviour (Feldman, Greenbaum, Mayes & Erhlich, 1997; Kaitz, Maytal, Devor, Bergman & Mankuta, 2010; Nicol-Harper, Harvey & Stein, 2007). For example, Nicol-Harper at al., (2007) conducted a study investigating the impact of maternal anxiety on mother-infant interactions in terms of maternal contribution. Sixty-four mothers and their ten to fourteen-month-old infants participated (Thirty-two in a high-trait anxiety group and thirty-two in a low-trait anxiety group). Mothers from a community sample were scored on anxiety traits using the Spielberger State-Trait Anxiety Inventory (STAI-T, Spielberger, 1983) and were assigned to the high trait anxiety group if they scored in the 70th percentile or above or the low-trait anxiety group is they scored in the 50th percentile or below. Each mother and infant was recorded in their home during a period of free play (without toys) followed by the infants being presented with a selection of toys. The mothers were then instructed to play with the toys presented and their child. Mothers were scored on behaviours such as sensitivity and emotional tone used. Results revealed that mothers in the high-trait anxiety group exhibited reduced maternal sensitive responsivity and lower emotional tone. This finding was also replicated by Feldman et al. (1997). Feldman and colleagues (1997) explored the relationship between mother-infant interaction and parental traits of anxiety. The authors found that a decrease in maternal trait anxiety was coupled with an increase in maternal sensitivity.

4.2.2.2. Infants of Anxious Mothers

Despite differences in maternal behaviour when the mother shows an increase of anxiety symptoms (Feldman et al., 1997; Kaitz et al., 2010; Nicol-Harper et al., 2007), there is general disagreement about the impact upon an infant's behaviour when their mother suffers from a mental disorder (Field, Diego, Hernandez-Reif, Shanberg & Kuhn, 2003). Kaitz et al. (2010) conducted a study aimed at identifying distinctive features of interactions between anxious mothers and their infants, in order to evaluate how maternal anxiety may affect infant behaviour. The sample consisted of ninety-three first time mothers and their six-month-old infants. Thirty-four women with a current diagnosis of an anxiety disorder formed the anxiety group. The remaining fifty-nine mothers did not meet criteria for an anxiety disorder and were placed in the control group. Mothers were filmed interacting with their infants during the Still-Face Paradigm (SFP) designed by Tronick, Als, Adamson, Wise and Brazelton (1978). Specifically, infants were observed in a three stage face-to-face interaction with an adult. In the first stage (baseline) the mother was told to interact with the infant normally. During the second stage (still-face) the mother remained in front of the infant but adopted a still-face and became unresponsive. In the third stage (reunion) the mothers resumed normal interaction. Infants were scored throughout each stage on their positive affect (smiling, laughing, etc), negative affect (crying, distress brow. etc.), and their gaze aversion. In addition, infants were observed during a play time interaction with a stranger. Kaitz et al. (2010) found that, during the SFP, mothers with higher anxiety scores exhibited exaggerated behaviour with their infant. The authors interpreted this as reflecting the hyperarousal that characterises most anxiety disorders. In addition, infants of anxious mothers were found to be less likely to show negative affect both during the still-face phase of the still-face procedure and during the play interaction with a stranger. Kaitz et al., (2010) explained these observed differences in behaviour as infants of anxious mothers employing different coping strategies for managing social challenges in comparison to their control counterparts, as a result of their mother's anxiety.

Further studies have also found differences in infant behaviour as a result of maternal anxiety (Blissett, Meyer & Haycraft, 2007; Stifter, Coulehan & Fish, 1993). For instance, Blissett et al. (2007) investigated the role of maternal psychopathology on infant eating behaviours. Ninety-six mothers and their infants (aged thirteen to forty-nine months) participated. Mothers completed a set of standardised questionnaires scoring them on eating disorders, anxiety, and depression, in addition to assessing their child's feeding behaviours in terms of food refusal and mealtime negativity. Results revealed that maternal anxiety was predictive of increased mealtime negativity, but only in boys. Additionally, Stifter et al. (1993) explored the effect of maternal separation on maternal interactive behaviour and infant attachment. Results revealed that mothers with high-trait anxiety traits exhibited intrusive behaviours towards their infant. In turn, infants of these mothers developed avoidant behaviours towards their mothers. This study's findings along with Blissett et al. (2007) provide a further insight into how infant behaviour is affected by mothers who exhibit anxiety traits.

4.2.2.3. Behaviour and frontal asymmetries

Despite anxiety disorders being increasingly common amongst women of child bearing age (Kessler, Keller, & Wittchen, 2001), only a limited number of studies have observed the effect of anxious mothers with their infants (Kaitz et al., 2010). However, as demonstrated by the current literature, high levels of maternal anxiety does affect maternal behaviour (Feldman et al., 1997; Kaitz et al., 2010; Nicol-Harper et al., 2007), which in turn has an impact upon infant behaviour (Blissett et al., 2007; Kaitz et al., 2010; Stifter et al., 1993). Frontal EEG asymmetries which show differences in power between the right and left frontal hemispheres have been associated with differences in adult and infant behaviour in terms of emotion regulation, temperament and approach and withdrawal behaviours

(Davidson, Ekman, Saron, Senulis & Friesen, 1990; Dawson, 1994; Dawson, Panagiotides, Klinger & Hill, 1992; Field & Diego, 2008; LoBue, Coan, Thrasher, & DeLoache, 2011). See Chapter 1, General Introduction (sections 1.3.2. and 1.4.) for further information on frontal asymmetries and personality traits. Furthermore, individuals with anxiety have been found to show differences in frontal asymmetry patterns in comparison to individuals who do not (Beaton et al., 2008; Fingelkurts, Fingelkurts, Rytsala, Suominen, Isometsa & Kahkonen, 2007; Thibodeau Jorgensen, & Sangmoon, 2006). This research suggests that differences in frontal asymmetry patterns could therefore be linked to the differences in behaviour exhibited by individuals who suffer from this disorder, their infants and their non-anxious counterparts. However, the current research does not provide an explanation as to whether behavioural differences are a result of differences in frontal asymmetries or whether differences in frontal asymmetries are a product of individuals displaying different behaviours (Allen, Urry, Hitt & Coan, 2004).

4.2.2.4. Frontal asymmetries, anxiety and depression

Despite the unknown causal relationship between frontal asymmetries and emotion based disorders, the stability of frontal asymmetries in individuals with depression requires further research (Allen et al., 2004). Differences in frontal asymmetries are believed to be predictor of risk for a variety of emotion based disorders such as depression and anxiety (Fingelkurts et al., 2007), with individuals who are not currently suffering from these disorders but who have a history of them showing a stability in their frontal EEG asymmetries (Allen et al., 2004). As previously mentioned, differences in frontal EEG asymmetries have been found to index trait tendencies within individuals in terms of approach or withdrawal behaviours (Coan & Allen, 2003; Davidson et al., 1990). Differences in frontal EEG asymmetry have been found in people who suffer from anxiety and depression when compared with people who do not (Beaton et al., 2008; Henriques & Davidson, 1991). These differences also tie in with previous findings on approach and withdrawal behaviours. Henriques and Davidson (1991) conducted a study to compare frontal EEG in depressed and non-depressed adults. The sample consisted of fifteen clinically depressed and thirteen non-depressed control participants. Two thirty second periods of baseline EEG data were collected, participants then watched a series of film clips designed to elicit emotions such as amusement, happiness, sadness, fear, disgust, and anger. The results revealed significantly greater right frontal brain activation in the depressed participant group relative to the control group. Greater right frontal asymmetry is coupled with withdrawal behaviours and emotions (Davidson et al., 1990), which in turn is related to the symptoms experienced by people with depression such as sadness and general withdrawal. Individuals who suffer from anxiety also display withdrawal behaviours, for instance, escape and avoidance of social situations in those with Social Phobia (Beaton et al., 2008). Beaton et al., (2008) conducted a study to examine frontal EEG asymmetry in 330 adults, some of whom suffered from the anxiety disorder Social Phobia. Participants were measured on self-reported shyness and sociability. They were given the task of delivering a two-minute presentation whilst an EEG recording was taken. Those individuals with a social phobia who self-reported a higher degree of shyness exhibited significantly greater right frontal brain activation. These findings provide further support for the notion that greater right frontal brain activation is coupled with withdrawal behaviours. Further to this, a meta-analytic study by Thibodeau Jorgensen and

Sangmoon (2006) supports the finding that depressive and anxious symptomatologies show strong relations with relative right frontal EEG asymmetry.

Recent studies have shown that mothers with depression also have an effect on their infant's frontal EEG asymmetry (Dawson, Frey, Panagiotides, Osterling, & Hessi, 1997; Diego, Field, Jones & Hernandez-Reif, 2006; Field & Diego, 2008; Jones, Field, & Almeida, 2009). Diego et al., (2006) examined EEG activity, interactive behaviours and socially inhibited behaviours in infants of depressed mothers. Sixty-six mothers and their infants participated in EEG measures at the neonatal period and at three to six months. Mothers were assigned to the depressed group if they met criteria for depression on the Center for Epidemiological Studies-Depression scale (CES-D; Radloff, 1977). They found that infants at both ages exhibited a distinct physiological profile; greater relative right frontal brain activation. These findings have been replicated by Jones et al., (2009) who looked at frontal asymmetries in infant of depressed and non-depressed mothers in twelve-month-olds. The notion of greater right frontal brain activation being associated with infants of depressed mothers is supported throughout the literature (see review Field & Diego, 2008). To date, no study has looked at the impact of maternal anxiety upon infant frontal asymmetries.

4.2.2.5. Aims and hypotheses

The main aim of this study was to investigate the impact of maternal trait anxiety on infant frontal asymmetries. In addition to the EEG data collected from infants in part one of this chapter, further participants were sought from The Barberry, National Institute for Mental Health (NIMH). This section required mothers to complete the Hospital and Anxiety

Scale (HADS; Zigmond & Snaith, 1983) to create an anxiety score for each participant. This allowed for mothers' anxiety scores to be examined in terms of their relationship to infant frontal EEG asymmetry scores (collected in part one) through a regression analysis. It was hypothesised that differences in frontal EEG asymmetries would only be apparent in the non-social condition and it was further hypothesised, that infants' brain functioning would be affected by the social nature of the stimuli such that trait measures, i.e. maternal anxiety, would not be reflected in the social condition. This was predicted as the results from part one of this chapter showed that greater left frontal brain activation was coupled with the social condition only and research has also demonstrated a link between social experiences and greater left frontal brain activation (Davidson et al, 1990; Dawson, 1994; Field & Diego, 2008). Next, as anxiety and depression commonly co-occur (Kaitz et al., 2010) it was predicted that greater right frontal activation would be significantly associated with greater anxiety scores in the non-social condition. As adults with and anxiety and depression show the same greater right frontal brain activation pattern (Beaton et al., 2008; Henriques & Davidson, 1991), it was predicted that infants of mothers with higher anxiety scores would also show this pattern of greater right frontal brain activation, replicating the activation seen in infants of depressed mothers (Dawson et al., 1997; Diego et al., 2006; Field & Diego, 2008; Jones et al., 2009).

A secondary aim of this study was to explore whether gender alongside anxiety scores will be predictive of frontal asymmetry scores. Blissett et al., (2007) found that male infants whose mothers have higher levels of anxiety have greater negativity at meal times. Therefore, it was hypothesised that there would be an association between male infants whose mothers have higher anxiety scores and greater right versus left frontal brain activation. However, as only a limited number of studies have observed the behavioural effect of anxious mothers with their infants (Kaitz et al., 2010) and studies do not generally include the gender of the child in their analyses (Blissett et al., 2007) the hypothesis has solely been formed on the basis of one study.

4.2.3. METHOD

4.2.3.1. Participants

Participants were infants aged between three and five months old who had been recruited via the Infant and Child Laboratory at the University of Birmingham. These participants were the same group of infants who participated in the social and non-social study in part one of this chapter. This section used the social and non-social EEG data generated from the previous study in addition to the demographic questionnaire results. In addition, further infants were recruited from The Barberry NIMH (see chapter 2, methods, section: 2.2. for further detail on recruitment). Parents recruited via The Barberry NIMH provided written consent for their child to participate after having the study explained to them by the experimenter. This consent had already been obtained for participants recruited via the Infant and Child Laboratory at the University of Birmingham. Infants received a complimentary toy for taking part. The current study involved collaboration with the NHS, through their research and development team to ensure recruitment of women from The Barberry NIMH. As previously mentioned in the chapter 2 (General Methodology), the three women recruited from The Barberry were excluded due to taking medication during pregnancy. Therefore the remaining sample was comprised of only participants from the community whose EEG data and demographic results were already available due to participation in the previous study.

As outlined in part 1 of this chapter, EEG data was available for seventy-two participants. Prior to statistical analysis, eighteen participants were excluded for having produced less than one minute of viable EEG data in either the social or non-social condition.

As a result, EEG data was available for fifty-four infants (30 female), with a mean age of 140 days. However, two mothers did not supply HADS data so they were not able to be included in the final analysis. Therefore, the final sample included fifty-two infants (28 female), with a mean age of 139 days (SD: 26.83).

4.2.3.2. Measures

EEG data and demographic information was already available for all potential participants. For further information on the existing measures and methods used to obtain this data please refer to Chapter 4 Part 1 (section 4.1.3.). In addition to this collected data, mothers were required to complete the Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983).The HADS is a self-assessment fourteen item scale which takes between two to five minutes to complete (Snaith, 2003). The HADS is a reliable instrument for detecting depression and anxiety, it was originally designed for use in hospital settings, however, this measure has been found to be reliable in assessing symptom severity of anxiety and depression in non-hospital groups (Bjelland, Dahl, Haug, & Neckelmann, 2002; McDowell, 2006).

The HADS has been criticised for its simplicity as it aims to categorise levels of anxiety and depression from fourteen items (Coyne & Sonderen, 2012). Furthermore, Coyne & Sonderen (2012) believe that the HADS is only useful as a measure of generalised distress, which is a key feature of these emotion based disorders. However, Coyne’s criticisms have particularly focused on the depression subset of the HADS and the current study employed the HADS for its anxiety subset. Furthermore, Norton, Sacker and Done (2012) have argued that the limitations addressed by Coyne & Sonderen (2012) are common amongst other self-screening instruments and not restricted to the HADS alone.

Despite criticisms of the HADS, this measure was deemed suitable for this study for several reasons. Firstly, the HADS is well established, convenient, fast to administer and has equally good sensitivity as other commonly used self-rating measures (Herrmann, 1997; Bjelland et al., 2002). Secondly, because the original sample consisted of women from the general community (non-hospital group) and women who were recruited from The Barberry, NIMH (hospital group), numerous authors have reported the reliability of the HADS in assessing symptom severity of anxiety and depression in the general population as well as in psychiatric settings (Bjelland, Dahl, Haug, & Neckelmann, 2002; McDowell, 2006). Additionally, the HADS can be re-administered at weekly intervals, which is an advantage for the current sample, as, the women recruited from The Barberry, NIMH may have previously completed the HADS or other self-screening instruments. Therefore, the current study administered the HADS to measure the severity and prevalence of maternal anxiety symptoms (see appendix item 2). Zigmond & Snaith's (1983) recommended cut-off scores were used to classify anxiety symptoms into the following levels: normal anxiety (0-7), mild anxiety (8-10), moderate anxiety (11-14), or severe anxiety (15-21).

4.2.3.3. Electrodes

Six left (as seen in figure 4.2.1.) and six right (as seen in figure 4.2.2.) frontal electrodes over the frontal scalp regions were selected for analysis (F3 and F4) in the alpha band (6-9Hz).

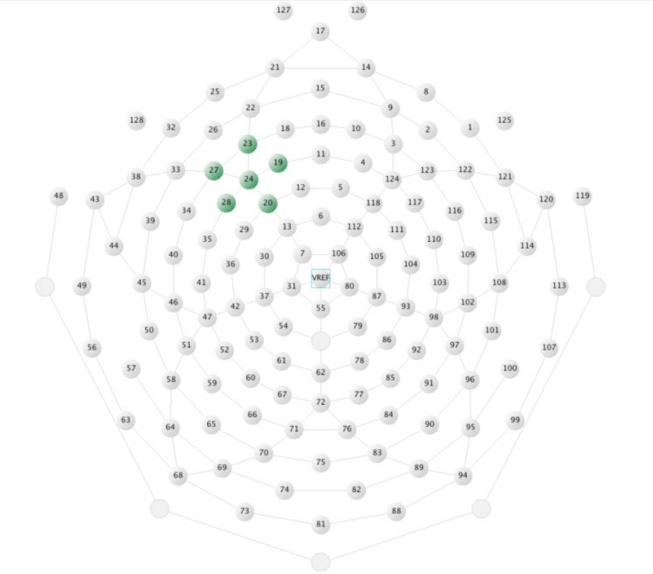

Figure 4.2.1. Left Frontal (F3)

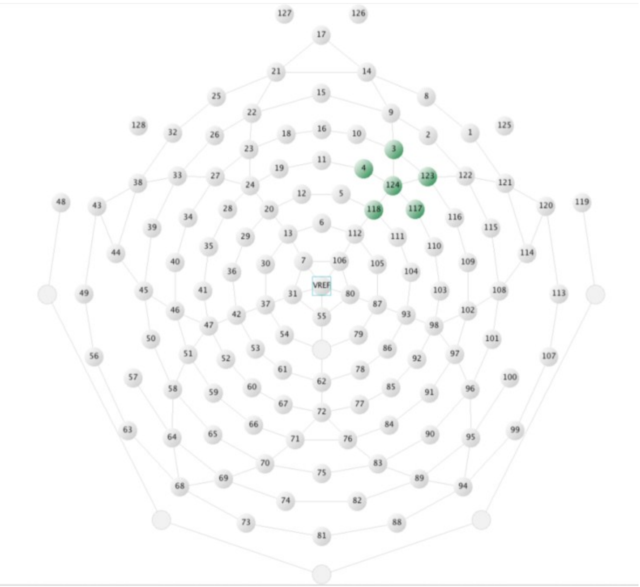

Figure 4.2.2. Right Frontal (F4)

4.2.4. RESULTS

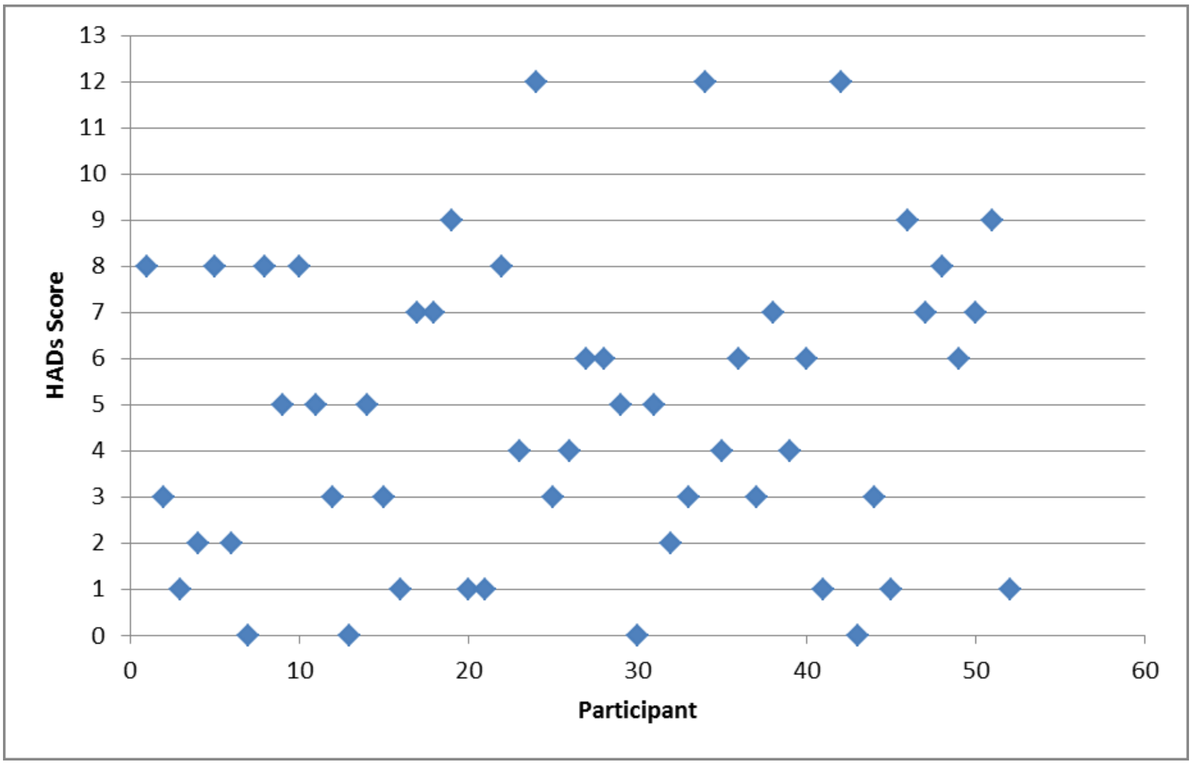

Figure 4.2.3. Participant by HADS scores. Although participants were not grouped into categories, the scatter graph illustrates the range of anxiety symptoms in the data set (normal anxiety, 40 (20 female); mild anxiety, 9 (5 female); moderate anxiety, 3 (3 female); severe anxiety, 0). In total, twelve mothers displayed higher than average anxiety levels.

4.2.4.1. Multiple Regression Analysis Dataset Diagnostics

Seven diagnostic tests were initially carried out to ensure that the social and non-social data set was suitable for multiple regression analysis.

4.2.4.1.1. Outliers

An analysis of standard residuals was carried out, which showed that the data contained no outliers (*Non-Social*: Std, Residual Min= -2.016, Std. Residual Max= 2.386; *Social*: Std, Residual Min= -1.746, Std. Residual Max= 2.595).

4.2.4.1.2. Collinearity

The data met the assumption of Collinearity, therefore indicating that multicollinearity was not a concern (*Non-Social*: Anxiety, Tolerance = 0.98, *VIF* = 1.01; Gender, Tolerance = 0.98, *VIF* = 1.02; Age, Tolerance = 0.98, *VIF* = 1.01; *Social*: Anxiety, Tolerance = 0.98, *VIF* = 1.01; Gender, Tolerance = 0.98, *VIF* = 1.02; Age, Tolerance = 0.98, *VIF* = 1.01).

4.2.4.1.3. Independent Errors

The data met the assumption of independent errors (*Non-Social*: Durbin-Watson value = 2.134; *Social*: Durbin-Watson value = 2.491) meaning that the residual terms (the difference between the actual asymmetry and predicted asymmetry for anxiety, age, and gender) in the regression were uncorrelated.

4.2.4.1.4. Random Normally Distributed Errors

The histogram of standardised residuals showed that the data contained normally distributed errors for both the social and non-social data. Additionally, the normal P-P plot of standardised residuals for both conditions supported this finding, with points either on the line or close to it.

4.2.4.1.5. Linearity and Homoscedasticity

The scatter plot of standardised residuals showed that the data for both conditions met the assumptions of homogeneity of variance and linearity.

4.2.4.1.6. Non-Zero Variances

The data also met the assumption of non-zero variances (*Non-Social*: Asymmetry, Variance = 0.011; Anxiety, Variance = 10.65; Gender, Variance =0.25; Age, Variance =720.38; *Social*: Asymmetry, Variance = 0.01; Anxiety, Variance = 10.65; Gender, Variance =0.25; Age, Variance =720.38).

4.2.4.2. Prediction of frontal asymmetries using hierarchical multiple regression analyses

All seven assumptions were met. Age was included in the analysis to control for the possibility of age-related impact on the results. Therefore, two hierarchical multiple regression analyses (enter method) were performed in order to evaluate the contributions of anxiety, gender, and age in predicting infant frontal asymmetry. Table 4.2.1. presents the descriptive results and table 4.2.2. presents the results of the regressions for the social and non-social conditions.

Table 4.2.1.

Mean asymmetry scores for both social and non-social conditions by gender and in total

	Condition	
Gender	**Social**	**Non-Social**
Male	0.036	0.032
Female	0.025	-0.023
Combined	0.027	0.001

4.2.4.2.1. Prediction of frontal asymmetry for the Non-Social condition

In the first model, levels of anxiety did not significantly predict infant frontal asymmetry scores (F (1, 50) = 0.013, p = 0.910, R^2 = 0.000). In the second step, anxiety and gender were marginally significant as predictive factors of asymmetry (F (2, 49) = 2.772, p =

0.072, $R^2 = 0.102$). T-tests revealed, however, that anxiety did not significantly predict infant frontal asymmetry (t (51) = 0.130, p = 0.897), whereas gender did, (t (51) = 2.352, p = 0.023). An independent t-test revealed that female infants had significantly greater right frontal brain activation in the non-social condition in comparison to their male counterparts ((t (50) = -2.375, p = 0.021) as shown in figure 4.2.4. In the final step, the regression was still not significant, (F (3, 48) = 1.859, p = 0.149, $R^2 = 0.104$). Age, did not contribute to the model as a significant predictor of asymmetry alongside anxiety and gender.

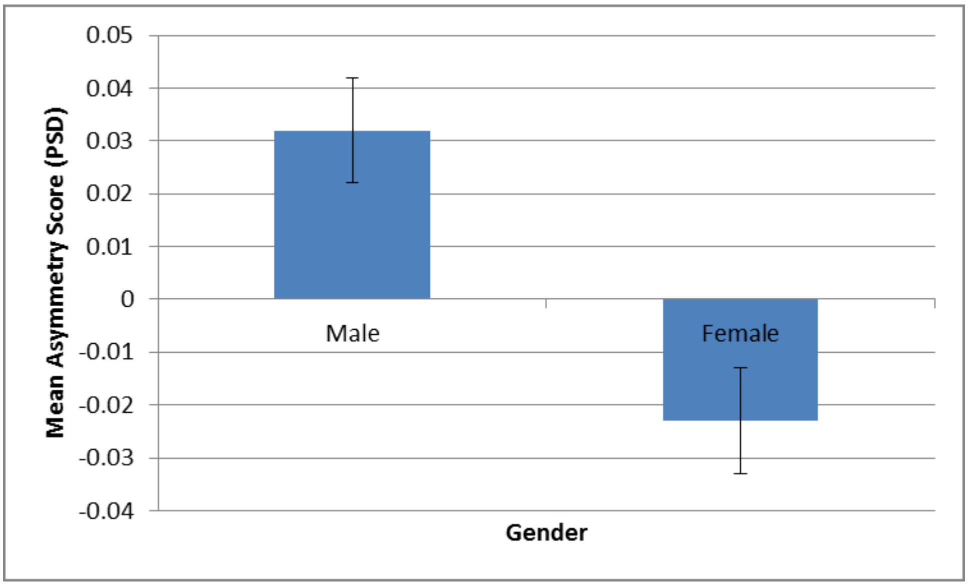

Figure 4.2.4. shows the mean asymmetry PSD values for male and females in the non-social condition. Error bars represent the standard error of the means. Females showed significantly greater activation than the males in the non-social condition ($p<0.05$). Note: an inverse relationship exists between PSD and activation, therefore a lower PSD reflects greater activation.

4.2.4.2.2. Prediction of frontal asymmetry for the Social condition

In the first model, anxiety was not a predictive factor for asymmetry (F (1, 50) = 0.012, p = 0.914, R^2 = 0.000). Gender did not significantly add to the model in the second step (F (2, 49) = 0.157, p = 0.855, R^2 = 0.006). Similarly, in the final step, age was also not predictive of asymmetry alongside anxiety and gender (F (3, 48) = 0.127, p = 0.944, R^2 = 0.008).

Table 4.2.2.

Hierarchical regression analyses to predict infant frontal asymmetry. * indicates p<0.05.

		Social Condition				Non-Social Condition			
		Model R^2	**Model R^2 change**	***t* for individual predictors**	***B for* individual predictors**	**Model R^2**	**Model R^2 change**	***t* for individual predictors**	***B for* individual predictors**
Model 1:	**Anxiety**	0.00	N/A	-0.11	0.00	0.00	N/A	-0.11	0.00
Model 2:	**Anxiety**			0.13	0.00			-0.17	-0.00
	Gender	0.10	0.10	2.35*	0.07	0.01	0.01	-0.55	-0.02
Model 3:	**Anxiety**			0.10	0.00			-0.14	0.00
	Gender			2.36*	0.7			-0.57	-0.02
	Age	0.10	0.01	0.36	0.00	0.01	0.00	-0.27	0.00

4.2.5. DISCUSSION

Adults with and anxiety and depression show greater right frontal brain activation (Beaton et al., 2008; Henriques & Davidson, 1991) and this same pattern is seen in infants of depressed mothers (Dawson et al., 1997; Diego et al., 2006; Field & Diego, 2008; Jones et al., 2009). To date however, the impact of maternal anxiety upon infant brain functioning has not been explored. Therefore, the main aim of the current study was to examine the effect of maternal anxiety symptoms upon infant frontal EEG asymmetry. Firstly, as hypothesised, a significant relationship was not found between anxiety symptoms and asymmetry in the social video observation condition. This was predicted as the previous chapter revealed greater left frontal EEG activation in the social condition, suggesting that infant brain functioning was influenced by the social nature of the stimuli. This previous finding coupled with the current study's finding therefore indicates that the social condition was reflecting the infant's level of interest (current state) as opposed to measuring for traits of anxiety so therefore was not a reliable measure of the anxiety and asymmetry relationship. Following on from this, it was hypothesised that the non-social condition would reveal a significant relationship between anxiety scores and asymmetry, more specifically, higher anxiety scores would be associated with greater right frontal brain activation in infants. Anxiety however, did not significantly predict infant frontal asymmetries. This prediction was based on studies that have shown that adults who have anxiety and depression show greater right frontal brain activation than people who do not suffer from these disorders (Beaton et al., 2008; Henriques & Davidson, 1991). Furthermore, infants of depressed mothers also show the same greater right frontal activation in comparison to their non-depressed counterparts (Dawson et al., 1997; Diego et al., 2006; Field & Diego, 2008; Jones et al., 2009). As anxiety and depression commonly co-occur (Kaitz et al., 2010) it was therefore predicted that the patterns in brain activation between depressed mothers and their infants would be mimicked in individuals with anxiety and their infants. In these studies however, mothers met the criteria for depression whereas the current study only looked at anxiety traits in a community sample. Forty mothers were classed as having normal levels of anxiety, nine mothers as having mild symptoms of anxiety, three mothers as having moderate levels of anxiety and no mothers reached criteria for severe levels of anxiety. Only twelve mothers in the present study had higher than normal anxiety levels, but these mothers only had traits of mild or moderate anxiety. The current study however, is useful in demonstrating that normal to moderate levels of anxiety within a community sample does not affect infant brain functioning.

A secondary aim of this study was to explore whether gender alongside anxiety scores was predictive of frontal asymmetry scores. It was hypothesised that male infants whose mothers have higher anxiety scores would be coupled with greater right frontal brain activation. Anxiety and gender together were found to be approaching significance in terms of their ability to predict infant frontal asymmetry. However, the analysis revealed that gender was the only predictive factor of infant frontal asymmetry, with females exhibiting significantly greater right frontal brain activation than males in the non-social condition. Although the hypothesis was not proven, the prediction was based solely on one study by Blissett and colleagues (Blissett et al., 2007). As previously mentioned, only a limited number of studies have observed the effect of anxious mothers with their infants (Kaitz et al., 2010) and studies do not generally include the gender of the child in their analyses (Blissett et al., 2007). Further to this, as the sample was based mostly on women with relatively normal levels of anxiety it is possible that gender effects may exist but not for lower levels of anxiety.

The current study also revealed that the females had significantly greater right frontal brain activation than boys in the non-social condition independent of their mother's anxiety score. This finding replicates the result found in the previous chapter and therefore was interpreted as it was previously, with females showing less enjoyment during the non-social condition in comparison to the social condition and consequently showing a withdrawn/negative reaction. Previous studies have found females to have a preference for social stimuli (Connellan et al., 2000; Lutchmaya & Baron-Cohen, 2002; Lutchmaya, Baron-Cohen & Raggatt, 2002). As females showed a significant negative and withdrawn brain response to the non-social condition, it is highly likely that this response would be reflected in their behaviour for this condition. Therefore, this is indicative that females would have a behavioural preference for the social condition over the non-social condition.

The major limitation of this study was the relatively normal levels of anxiety within the sample that participated. Only three mothers out of fifty-two met criteria for anxiety, with the majority of the sample being categorised in the normal anxiety range. Although previous studies looking at mother-infant interaction in anxiety have also used community samples (Blissett et al., 2007; Feldman et al., 1997; Nicol-Harper at al., 2007; Stifter et al., 1993), a significant portion of those samples have met criteria for anxiety disorders. Therefore the current study was not very representational in terms of exploring the effect of serious or concerning symptoms of anxiety in the mother on infant brain functioning. Although it was attempted, the current study was not successful in recruiting a large sample of women with a diagnosis of anxiety due to limited resources. Future work in this area should focus on obtaining a larger sample, through expanding the number of hospitals that women are recruited from, ensuring that the sample is enriched with women who meet a current diagnosis of an anxiety disorder. This would allow for the exploration of whether infant brain functioning is affected in cases where the mother is experiencing serious and affecting anxiety symptoms, as opposed to normal range and mild to moderate sub-clinical anxiety symptoms.

A second limitation of this study was that the effect of depression was not explored alongside anxiety. As anxiety and depression commonly co-occur (Kaitz et al., 2010) and a mothers depression has been shown to effect their infants brain functioning (Dawson et al., 1997; Diego et al., 2006; Field & Diego, 2008; Jones et al., 2009) it would have been beneficial to see if depression symptoms would have impacted this studies results. Another future direction for this study would be to explore this relationship. This point is discussed in further detail below.

A third limitation of the current study was the use of the HADS to measure the severity and prevalence of maternal anxiety symptoms within the current sample. This measure was chosen as numerous authors have reported the reliability of The HADS in assessing symptom severity of anxiety within the general population as well as in psychiatric settings (Bjelland, Dahl, Haug, & Neckelmann, 2002; McDowell, 2006). Despite being deemed an appropriate measure at the time of the study, the HADS has been criticised as being too simplistic a measure of anxiety (Coyne & Sonderen, 2012) and does not take into consideration various types of anxiety disorders. There are a range of anxiety disorders, including Generalised Anxiety Disorder (GAD) Social Phobia, Post Traumatic Stress Disorder (PTSD), Panic Disorder and Obsessive Compulsive Disorder (OCD: American

Psychiatric Association, 2013). Therefore, the use of the HADS may have been too broad of a measure of anxiety as it does not account for specific types of anxiety disorders, for example, items on the HADS may not account for the range of symptoms seen within differing anxiety disorders. A future direction for this study could be to include a more specific measure of anxiety disorders for instance The Psychiatric Diagnostic Screening Questionnaire (PDSQ: Zimmerman and Mattia, 1999). Although the PDSQ is more time consuming to complete, it covers a range of anxiety disorders, is widely used in outpatient mental health and has excellent levels of reliability and concurrent validity (Zimmerman & Mattia, 2001). The PDSQ would also allow for the comparison of brain activation between anxiety disorders, to see if differences exist. This would be beneficial in allowing researchers to obtain a greater understanding of impact of different anxiety disorders in the infant brain. Furthermore, if certain anxietydisorders have a greater impact on infant brain functioning, this could be an indication of possible high-risk groups who would benefit from intervention. As a result, this further research could impact on intervention services offered in cases of maternal anxiety in an effort to encourage more typical mother-infant interactions styles.

Additionally, as previously discussed, it would be beneficial to include a measure of depression, as depression and anxiety commonly co-occur (Kaitz et al., 2010). Although depression levels can be measured using the HADS, if a more rigorous measure of anxiety is to be adopted then it is advisable to remain consistent will all measures. The PDSQ also includes a scale for the measurement of Major Depressive Disorder (MDD) which is deemed as reliable and valid within the field (Zimmerman & Mattia, 2001) and would therefore be suitable for future studies. Including a depressed subset would allow researchers to understand the neurophysiological presentation of depression and anxiety to a greater degree.

The implication of this further research would be possible identification of whether both disorders or one in isolation leads to greater differences upon infant frontal asymmetries. This could indicate which groups of individuals would benefit from early behavioural interventions, for example, interventions could be created to increase typical interactions between mother and infant. For instance, Field et al (2003) found that depressed mothers with good interaction styles in comparison to withdrawn or intrusive interaction styles had infants who displayed more typical behaviours. Increasing typical behaviours earlier on could potentially have a positive impact on later behaviours.

In conclusion, the current study did not find mothers' trait anxiety to predictive of infant frontal EEG asymmetry profiles. Anxiety symptoms were also not predictive of frontal EEG asymmetry when age and gender of the infants were included as potential modifying factors. This finding is useful in providing preliminary evidence to suggest that normal to moderate levels of anxiety symptoms within a typical community sample do not significantly or negatively affect infant brain functioning. Future work is needed in order to more fully and directly explore the effect of maternal anxiety on infant brain functioning. This would involve increasing the sample size and including an enriched sample of mothers who meet criteria for a clinical diagnosis of an anxiety disorder.

CHAPTER 5

META-ANALYSIS: DEPRESSION AND THE STILL-FACE PARADIGM

5.0 RATIONALE

This final experimental chapter will move on to explore the effects of depression upon infant behaviour. So far, the thesis has explored the effects of auditory and visual social and non-social stimuli upon infant brain functioning in infancy. Both chapter 3 (Speech and Non-Speech Processing in Infants) and part one of chapter 4 (Social and Non-Social Processing in Infancy) found infant brain functioning to be influenced by the social nature of the stimuli. This finding is important as measurements of resting infant EEG asymmetries usually rely upon a mixture of social and non-social methods, leaving open the possibility that the social nature of the stimuli are affecting study results (see part 1 of Chapter 4 for further discussion). This possible confound was explored further in part 2 of chapter 4 by looking at the effect of this methodology upon infant frontal asymmetries when maternal anxiety was factored in. As before, the social nature of the stimuli influenced results however, infant frontal asymmetry patterns were not found to be affected by maternal levels of anxiety.

Despite the previous chapter not finding a significant difference, it is important to consider the impact of depression and anxiety upon the infant brain. This will allow for an increased understanding of the biological role of these disorders in addition to the potential impact of methodologies used to measure frontal asymmetries. Furthermore, the behavioural impact upon infant behaviour also needs to be considered in order to make links between brain and behaviour within emotion based disorders. If behavioural differences are found for infants of mothers with emotional based disorders, care providers will be in a better position to provide a higher quality of informed support for these infants and their mothers.

Research has demonstrated that mothers with emotionally based disorders will interact differently with their child (Cohn, Campbell, Matias, & Hopkins 1990; Field, Healy, Goldstein, & Guthertz, 1990; Diego et al., 2006). Furthermore, evidence has shown that infants will also show behavioural differences when compared to infants of mothers without these disorders (Cohn, Campbell, Matias, & Hopkins 1990; Field, Healy, Goldstein, & Guthertz, 1990; Diego et al., 2006; see Chapter 1 section 1.4. for further information). Despite reported differences in infant behaviour being found there is not a general consensus about what this behaviour is within the literature (Mesman et al., 2009). Although the previous chapter explored the effect of anxiety upon infant brain functioning, the behavioural research regarding infants of anxious mothers is limited and the existing studies rely upon different methodologies, which does not allow for the possibility to compare behavioural results across studies. However, numerous studies within the depression literature have adopted the same paradigm to measure mother-infant interaction, the Still-Face Paradigm (Tronick, Als, Adamson, Wise & Brazelton, 1987). The use of this measure between these studies means that a meta-analysis can be performed. This will provide the field with an objective and informative overview of behaviour displayed by infants of depressed mothers.

5.1. ABSTRACT

The Still-Face Paradigm (SFP:Tronick, Als, Adamson, Wise and Brazelton,1978) is a useful paradigm which enables researchers to examine the quality of mother-infant interactions (Guesella, Muir & Tronick, 1988). The SFP has been used to explore the effect of maternal depression upon infant behaviour (Mesman et al., 2009). In typical infants, a classic Still-Face Effect has been confirmed which involves infants demonstrating reduced positive affect (PA), reduced gaze (GA), and increased negative (NA) affect during the Still-Face period that is carried over into the Reunion stage (Mesman et al., 2009). However, the behavioural responses of infants of depressed mothers remains unclear. The aims of this current study were to see if infants of depressed mothers demonstrate the classic still-face effect and if they display the same levels of Positive Affect, Negative Affect, and Gaze Aversion as their counterparts with non-depressed mothers. Meta-analyses were conducted on seven studies on depression and the SFP to explore these aims. Results revealed that infants of depressed mothers display the classic still-face effect like infants of their non-depressed counterparts. However, the infants of depressed mothers also demonstrated significantly higher levels of PA during the still-face episode than infants of non-depressed mothers. Potential interpretations of these findings is that due to their prior experience of similar, depressed interactions with their mothers, the infants of depressed mothers amplify their positive attachment signals to engage maternal attention and response or are using PA in order to regulate their NA. Future directions for this study would be to conduct studies with other caregivers and with individuals of which the infant has no prior experience. This would investigate whether coping strategies are only employed with their depressed mothers or whether this behaviour is a learnt response which is generalised towards all individuals.

5.2. INTRODUCTION

The Still-Face Paradigm (SFP), designed by Tronick, Als, Adamson, Wise and Brazelton (1978) has been used in large number of studies and is a useful paradigm which enables researchers to examine the quality of mother-infant interactions (Guesella, Muir & Tronick, 1988). In the SFP infants are typically observed in a three stage face-to-face interaction with an adult (see Mesman, Ijzendoorn & Bakermans-Kranenburg, 2009, for review). The first stage (Baseline) is a typical face-to-face interaction episode in which the adult is told to interact with the infant as they normally would. The second stage (Still-Face) involves the adult remaining in front of the infant but adopting a still-face and becoming unresponsive. The third stage (Reunion) involves the adult resuming normal interaction with the infant. Infants are scored throughout each stage on their positive affect (e.g., smiling, laughing), negative affect (e.g., crying, distress brow), and their gaze aversion (i.e., gaze away from adult). The SFP assesses an infant's behavioural response to a reduction in responsiveness from a caregiver (Stanley, Murray, & Stein, 2004), and is believed to be a reliable method for inducing stress in young infants, enabling the observation of emotion regulation in a social context (Field, Vega-Lahr, Scafidi & Goldstein, 1986; Manian & Bornstein, 2009). A recent meta-analysis by Mesman and colleagues (2009) confirmed the existence of a classic Still-Face Effect (SFE), which involves infants demonstrating reduced positive affect, reduced gaze, and increased negative affect during the Still-Face period that is carried over into the Reunion stage (Mesman et al., 2009).

The SFP has also been used to investigate the effects of maternal psychopathology on mother-infant interaction (Mesman et al., 2009), with the majority of studies focusing on maternal depression. Infants who have experienced different or inconsistent interactions with caregivers as a result of parental depression may fail to show the classic still-face effect (Moore, 2001). Attachment theorists have argued that the quality of day-to-day interactions between a primary caregiver and an infant help the infant develop an internal emotional-cognitive template. This template, they suggest, underpins how the infant then interacts emotionally and behaviourally with their caregiver (Bretherton, 1992; Ainsworth & Bowlby, 1991). Significant associations have often been reported between depression and maternal behaviour during the SFP, with depressed mothers being less behaviourally sensitive and more emotionally disengaged with their infants, in addition to displaying higher levels of negative affect (Field, 1994; Field, 2002; Field, Hernandez-Reif, Diego, Feijo, Vera, Gil, et al., 2007; Rosenblum, McDonough, Muzik, Miller & Sameroff, 2002; Stanley, Murray & Stein, 2004; Weinberg, Olson, Beeghly, & Tronick, 2006). However, differing results have been found in relation to infant responding during the SFP (Mesman et al., 2009).

Some authors have found that the SFP is less distressing for infants of depressed mothers. For example, Field and colleagues (2007) used the SFP to explore separation effects between infants of depressed and non-depressed mothers. Infants of depressed mothers appeared to find the paradigm less distressing as evidenced by fewer negative behaviours, less gaze aversion, and less motor activity during the still-face period. Similar results were found earlier by Field (2002), using an adapted version of the SFP. Depressed and non-depressed mothers were instructed to act depressed in place of the still-face episode. Infants of depressed mothers overall had less positive behaviours but showed little change in behaviour during the depressed period. The results of a study by Pelaez-Nogueras, Field, Hossain and Pickens (1996) provide similar evidence. Infants of depressed mothers were found to have less negative and more positive behaviours in comparison to infants of non-depressed mothers at the Reunion stage. Pelaez-Nogueras and colleagues interpreted these findings as indicating that infants of depressed mothers recover faster from the still-face period due to being less distressed initially (Pelaez-Nogueras et al., 1996). The authors, therefore, suggest that infants of depressed mothers are familiar with their mother's disengaged, depressed behaviour and, so, are thereby less distressed than their non-depressed counterparts during the SFP.

Authors have suggested that infants of depressed mothers develop a passive coping style much like that of infant primates (Field, 2002; Reite, Short, Seller & Pauley, 1981). In 1981, Reite and colleagues observed infant primates and their level of control in stressful situations. The authors found during brief moments of stress, active coping was adopted by the infants through agitated behaviour and physiological arousal. Alternatively, during lengthened periods of stress, the primate infants passively coped, which was indexed through reduced physiological and physical responses. Based upon these findings, Field (2002) has argued that infants of depressed mothers may develop passive coping strategies through repeated exposure to depressed interactions with their mothers, aiding them in becoming less distressed during the SFP. Field (2002) also found infants of depressed mothers displayed more positive behaviours and less negative behaviours during still-face and reunion periods. Out, Bakermans-Kranenburg and Van Ijzendoorn (2009) have suggested that infants with disorganised attachment styles (due to a range of factors including maternal insensitivity and maternal psychopathology) will attempt to minimise the expression of negative emotions in an attempt deal with stressful circumstances and to engage with their mother. Additionally, Weinberg and Tronick (1996) have suggested that PA may be an effective way for infants to deal with the still-face, by down-regulating the feelings of the distress it induces. It is therefore possible that infants of depressed mothers are amplifying their positive attachment signals in these circumstances to attract maternal attention and response or are using PA in order to regulate their NA.

The view that infants of depressed mothers adopt coping strategies to deal with the stress induced by the SFP is supported throughout the literature (Manian & Bornstein, 2009, Moore, Cohn, and Campbell, 2001). Moore et al., (2001) found infants of depressed mothers had increased gaze aversion, at 4 months. Gaze aversion acts as an important emotion-regulation strategy in infancy, allowing the infant to disengage from the source of distress (Manian & Bornstein, 2009). The authors suggest that the infants of depressed mothers increase their gaze aversion in a bid to manage their distress during the SFP more effectively. Manian and Bornstein (2009) have found contradictory results however, infants of non-depressed mothers significantly averted their gaze less often. Despite this contradictory finding, the authors believe this is evidence of a coping strategy, however, as the infants of depressed mothers in their study appeared to adopt self-soothing strategies, as opposed to averting their gaze to regulate their distress.

In other instances, infants of depressed mothers have been found to exhibit increased negative behaviours in comparison to infants non-depressed mothers in the SFP (Forbes, Cohn, Allen, & Lewinsohn, 2004; Rosenblum et al., 2002; Weinberg et al., 2006). This finding however, was not consistent across age and gender of infants of depressed mothers, or current depressive symptoms of the depressed mothers. Furthermore, Forbes and colleagues (2004) found increased negative affect only in infants who had parents with a previous diagnosis of depression in comparison to mothers who have never had a diagnosis, and negative affect was not significantly associated with current depressive symptoms. Similarly, Rosenblum and colleagues, solely found increased negative affect in 3 month old infants of depressed mothers in comparison to infants to non-depressed mothers (Rosenblum et al., 2002), whilst Weinberg and colleagues found that increased negative behaviours were only evident in male infants of depressed mothers (Weinberg et al., 2006). Weinberg et al., (2006) proposed that the Mutual Regulation Model (MRM, Tronick & Weinberg, 2000) accounted for this observed increase in negative behaviour. In this model negative behaviours become more apparent and reinforced in an infant due to a cycle of negative interactions between mother and child (Weinberg et al., 2006).

Evidence has also been presented to support the notion that infants of depressed mothers display the classic still-face effect (Moore and Calkins, 2004; Stanley et al., 2004; Weinberg, Beeghly, Olson and Tronick, 2008). Weinberg et al., (2008) for example, evaluated the interactive behaviour of depressed mothers and their infants using the SFP. Results indicated that infants of depressed mothers displayed the traditional still-face effect (SFE) and, therefore, did not differ from infants with mothers without a clinical diagnosis. Similarly, Stanley and colleagues (2004), as well as Moore and Calkins (2004), did not find any significant differences in infant behaviour between their depressed and non-depressed groups. The authors, therefore, suggest that infants of depressed mothers find the SFP equally distressing as infants of non-depressed mothers.

As can be seen from this literature review, the nature and extent of any differences in the responses of infants of depressed versus non-depressed mothers during the SFP is currently unclear. It appears that depressed mothers interact differently with their infants during the SFP (Field, 1994; Field, 2002; Field et al., 2007; Rosenblum et al., 2002; Stanley et al., 2004; Weinberg et al., 2006). Furthermore, several studies have reported that infants of depressed mothers find the SFP less distressing (Field 2002; Field 2007; Pelaez-Nogueras, Field, Hossain & Pickens, 1996), that they have increased/decreased gaze aversion (Manian & Bornstein 2009; Moore et al., 2001), or increased negative behaviours (Forbes et al., 2004;

Rosenblum et al., 2002; Weinberg et al., 2006).. At the same time, however, several studies have also found little to no difference in the behavioural responses of infants with depressed versus non-depressed mothers, and finding that infants of depressed mothers display the classic SFE (Moore & Calkins, 2004; Stanley et al., 2004; Weinberg et al., 2008; see also Mesman et al., 2009).

The first aim of the current study was to determine whether or not infants of depressed mothers display the classic Still-Face Effect when compared infants of the non- group. The second aim was to investigate whether or not infants of depressed mothers display the same levels of behaviour (positive affect, negative affect, and gaze aversion) as their counterpart infants of non-depressed mothers, for each episode of the SFP. To these ends, an initial meta-analysis was conducted on the infants of the non-depressed groups to confirm or disconfirm the classic still-face effect before the depressed group's behaviour was directly compared. It was hypothesised that this first meta-analysis would confirm the classic SFE in the non-depressed group as the SFE in typical infants is widely accepted within the literature and was recently confirmed in a meta-analysis by Mesman (2009). A second meta-analysis was performed to directly compared changes in positive affect (PA), negative affect (NA), and gaze aversion (GA) in infants of depressed and non-depressed mothers between each of the still-face episodes. The purpose of this meta-analysis was to see if infants of depressed mothers would also display the same changes in pattern of behaviour across episodes as the infants of the non-depressed mothers. Two possible outcomes were identified. Firstly, that the infants of depressed mothers would display the classic SFE, reflecting the results of previous studies, indicating that the infants find the SFP distressing (Stanley et al., 2004; Weinberg et al., 2008). Secondly, it was possible that the infants of depressed mothers would show group differences during the SFP as Field (2007) and Pelaez-Nogueras et al. (1996) found which would indicate that the infants find the SFP overall a less distressing experience. Following these meta-analyses, a third meta-analysis was conducted to directly compare the behaviours of infants of depressed versus non-depressed mothers during each of the stages of the SFP. The aim was to see if levels of behaviour displayed by infants of depressed mothers differed from infants of non-depressed mothers for each individual episode of the SFP. Specifically, we directly compared levels of PA, NA and GA between the groups for each SFP episode. Due to the mixed findings within the literature several hypotheses were formed. Firstly, that infants of depressed mothers would display increased levels of negative behaviour overall as this finding has been supported by several authors (Forbes et al., 2004; Rosenblum et al., 2002; Weinberg et al., 2006). Another supported possible outcome would be that infants of depressed mothers would show differences in their gaze as a coping strategy (Moore et al., 2001; Manian et al., 2009). Lastly, it was hypothesised that infants of depressed mothers would show an increase in positive behaviours during the Still-Face and Reunion episodes (Field, 2002; Field, 2007; Pelaez-Nogueras et al., 1996).

5.3. METHOD

5.3.1. Selection of studies

Web of Science (http://wok.mimas.ac.uk) was used to perform forward and backwards searches. Initially, a forward and backward search was performed on the Mesman et al. (2009) paper to identify studies which were cited in this review and studies which had cited this key paper as well. Following this, studies were selected for inclusion in the current meta-analyses if they presented data using the still-face paradigm with infants of mothers with depression. Further forward and backward searches were performed on these selections to ensure all relevant studies were identified. Data from groups of infants with non-depressed mothers were used as control groups in all of the included papers, in order to confirm the existence of the classic SFE, a study did not need to have a control group to ensure inclusion. Further to this, for a study to be included it needed to have reported infant behaviours which could be grouped into PA, NA, or GA. This ensured that direct comparisons could be made for the behaviour of infants of depressed versus non-depressed mothers at each stage of the SFP.

Studies also had to report either the average portion of time or the average percent of time infant behaviour occurred in each episode. For the current study, all behaviours were converted to the average percent of time behaviour occurred, providing a consistent measurement of infant behaviour to be used in the meta-analyses. In addition, standard deviation or standard error had to be included, as this statistical information was required for the meta-analyses.

In cases where the above information was not available, the corresponding author was contacted and requested to supply this information (Moore & Calkins, 2004; Moore et al., 2001; Weinberg et al., 2008). From a possible eleven studies, four were excluded for the following reasons. Unfortunately, data no longer existed for Field's study (1984, republished again in 2002) so this paper was unable to be included. Authors responsible for correspondence in Weinberg et al. (2006) and Rosenblum et al.'s (2002) papers declined to share their data, whilst Forbes (2004) became un-contactable after a brief communication. Therefore, data from these studies could not be included in the analyses. This left a final number of seven studies for the meta-analyses as shown in table 5.1.

Table 5.1.

Included studies, number of infants and mean age by depressed and non-depressed groups

	Non-Depressed		**Depressed**	
Study	**Number of Infants**	**Mean Age (months)**	**Number of Infants**	**Mean Age (months)**
Stanley at al. 2004	50	3	72	3
Manian & Bornstein 2009	68	5	48	5
Moore 2004	60	3	13	3
Moore et al. 2001	62	4	67	4
Field 2007	16	4	16	4
Pelaez-Nogueras et al. 1996	16	3	16	3
Weinberg et al. 2008	48	3	33	3

5.3.2. Meta-analytic Procedures

Three meta-analyses were conducted, the initial meta-analysis was performed on the non-depressed groups to confirm or disconfirm the classic still-face effect before the infants of depressed mothers' behaviour was directly compared to the infants of non-depressed mothers. A second meta-analysis was conducted to directly compare PA, NA and GA across the SFP in infants of depressed and non-depressed mothers. The final meta-analysis also compared PA, NA and GA between the infants of depressed and non-depressed mothers' but for each stage of the SFP separately. All meta-analyses were performed in STATA 11 (StataCorp: College Station TX).

5.3.3. Meta-analysis 1: The Still-Face Effect in infants of non-depressed mothers

The aim was to investigate whether the classic still-face effect was present in the infants of non-depressed mothers before direct comparisons were made with the infants of depressed mothers. Therefore, changes in PA, NA, and GA between each of the still-face episodes in the control groups (infants of non-depressed mothers) were examined with an initial meta-analysis.

5.3.3.1. Collapsing behaviours

Percentage of time behaviours occurred was calculated for each study to ensure the measure of infant behaviour was the same for each included study (Forbes 2004, Moore 2001 & 2004).

Mean differences and standard errors were calculated for changes in each behaviour, between each stage. For example: smiling (baseline) - smiling (still-face), smiling (baseline) - smiling (reunion) and smiling (still-face) - smiling (reunion). This allowed us to see changes in behaviour across each stage of the paradigm.

Many studies included several infant behaviours, for example PA may have been represented by smiling and positive vocalisations (see Table 6.2). These variables were combined using a fixed effects model as it was assumed that the variation in a study's sample would be consistent for behaviours within that study (Lipsey & Wilson, 2001). Values for the average percentage of time PA, NA and GA occurred were computed for infants of depressed mothers. Upper and lower confidence intervals (CIs) were also generated for each study and behaviour. Pooled standard errors were estimated based on CIs.

5.3.3.2. Random effects model

Nine meta-analyses were performed using a random effects model.

5.3.4. Meta-analysis 2: Direct comparison of behavioural changes across episodes

The second meta-analysis directly compared changes in behaviour (PA, NA, and GA) across each episode of the SFP between the infants of depressed and non-depressed mothers. Values for the collapsed behaviours and pooled standard errors were computed the same way for the infants of depressed mothers as they were in the first meta-analysis (Table 6.2. indicates collapsed behaviours).

Mean differences for the infants of depressed mothers were subtracted from the mean differences of the infants of non-depressed mothers. Standard errors were computed accordingly for the final mean difference values. Nine meta-analyses using the mean differences and pooled standard errors were performed using a random effects model. A direct comparison of infants of depressed and non-depressed mothers were made by looking at changes in PA, NA and GA between each still-face episode (baseline-still-face, still-face-reunion and baseline-reunion). Combined *p*-values, effect sizes (d) and 95% CIs were generated. Positive effect sizes reflected a higher occurrence of behaviour in the control groups and negative effect sizes reflected a higher occurrence of behaviour in the depressed groups.

5.3.5. Meta-analysis 3: Direct comparison of behaviour for each episode

The third meta-analysis directly compared behaviours (PA, NA, GA) for the infants of depressed and non-depressed mothers for each episode of the SFP (Baseline, Still-Face and Reunion).

The percentage of time infant behaviours occurred at each episode and their corresponding standard errors were entered into a fixed effect model. As before, this allowed behaviours to be collapsed into the PA, NA and GA categories for each study (see table 6.2. for collapsed behaviours).

Mean percentage of time of PA, NA and GA for the depressed groups were subtracted from the mean percentage of time of PA, NA and GA for the control groups in each of the still-face episodes. Standard errors for each study and behaviour were computed. Nine meta-analyses using the mean differences and the pooled standard errors were performed using a random effects model, combined *p*-values, effect sizes (d) and 95% CIs were generated. Positive effect sizes reflected a higher occurrence of behaviour in the control groups and negative effect sizes reflected a higher occurrence of behaviour in the depressed group.

Table 5.2.

This table shows each study that contributed to the meta-analyses. Behaviours are listed for each study, which were subsequently collapsed in the initial stages to provide individual scores for PA, NA and GA for each episode of the SFP. The table indicates with (-) where behaviours did not need to be collapsed as singular measure were already available for PA, NA and GA. The table also indicates where data was not available.

	Positive Affect			Negative Affect			Gaze Aversion		
Studies	**Baseline**	**Still-Face**	**Reunion**	**Baseline**	**Still-Face**	**Reunion**	**Baseline**	**Still-Face**	**Reunion**
Stanley et al. (2004)	-	-	-	Protest to mother Dysregulation Avoidance of mother	Protest to mother Dysregulation Avoidance of mother	Protest to mother Dysregulation Avoidance of mother	-	-	-
Manian & Bornstein (2009)	-	-	-	Wary Negative Affect	Wary Negative Affect	Wary Negative Affect	-	-	-
Moore & Calkins (2004)	-	-	-	-	-	-	-	-	-
Moore et al. (2001)	-	-	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available
Field (2007)	Smile Vocalisations	Smile Vocalisations	Smile Vocalisations	Distress Brow Crying	Distress Brow Crying	Distress Brow Crying	-	-	-
Pelaez-Nogueras et al. (1996)	Smile Gaze Vocalisations	Smile Gaze Vocalisations	Smile Gaze Vocalisations	Grimace Crying	Grimace Crying	Grimace Crying	-	-	-
Weinberg et al. (2008)	-	-	-	-	-	-	-	-	-

5.4. RESULTS

5.4.1. Meta-Analysis 1

The purpose of this meta-analysis was to see if infants of non-depressed groups showed the classic SFE as confirmed throughout the literature (Mesman et al., 2009). The initial meta-analysis confirmed the classic still-face effect in the infants of mothers without depression (i.e., the control group). Positive affect significantly reduced from the baseline to the still-face episode ($p<0.01$) with significantly lower positive affect at the reunion episode in comparison to baseline ($p<0.05$) as shown in figures 5.1. and 5.2.

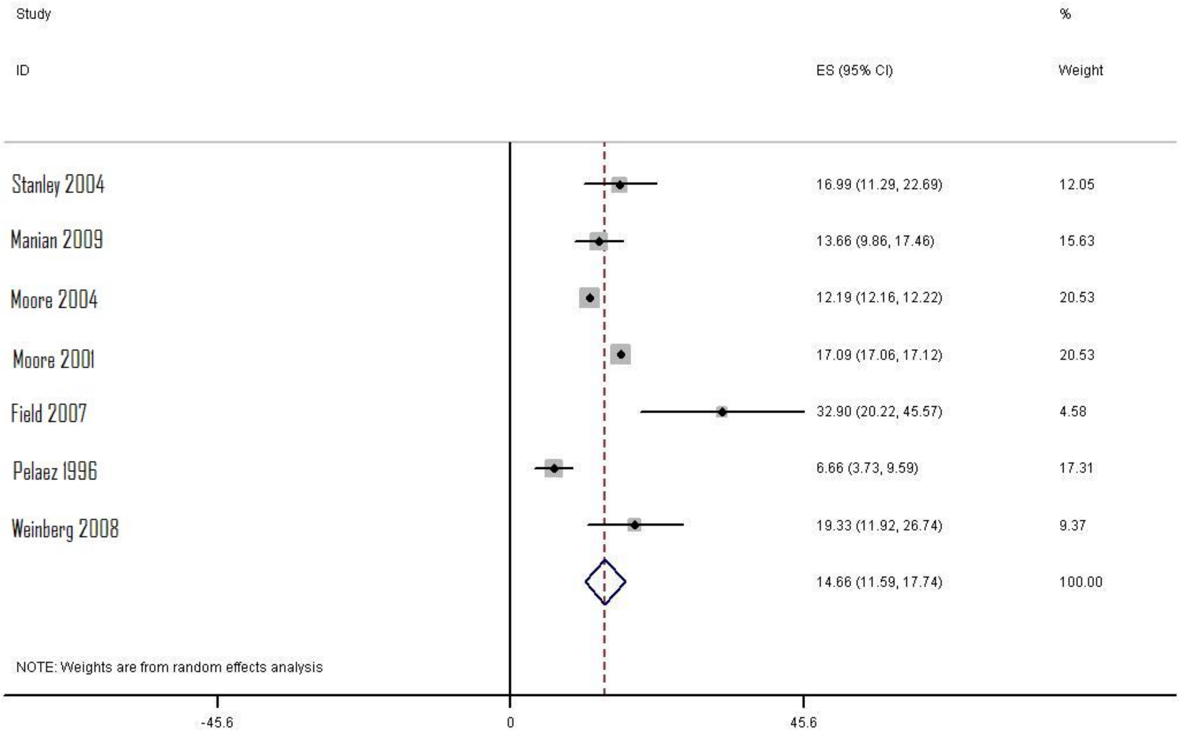

Figure 5.1. PA from baseline to still-face episode. A significant reduction is seen by the confidence intervals of the overall PA being positioned to the right of the forest plot and not touching the solid vertical line of no effect (p<0.01).

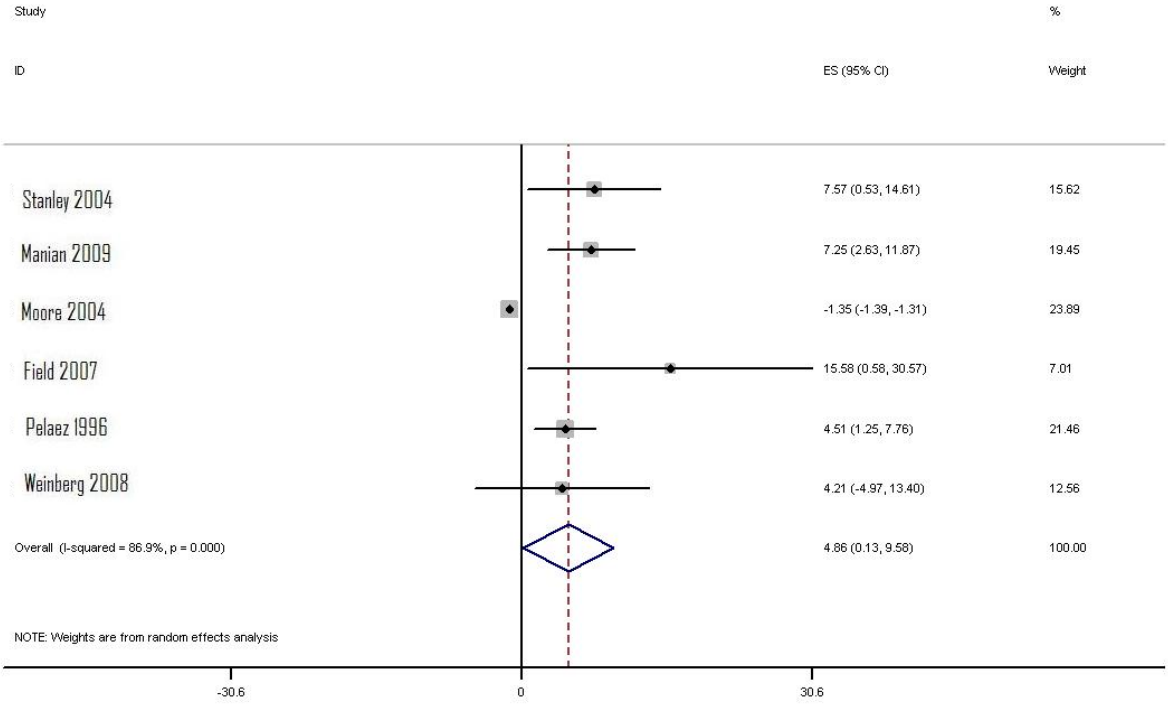

Figure 5.2. PA from baseline to reunion episode. A significant reduction is seen for PA from baseline to reunion episode by the confidence intervals of the overall PA being positioned to the right of the forest plot and not touching the solid vertical line of no effect (p<0.05).

Negative affect (p<0.01) and gaze aversion (p<0.01) significantly increased from baseline to still-face as shown in figures 5.3 and 5.4.

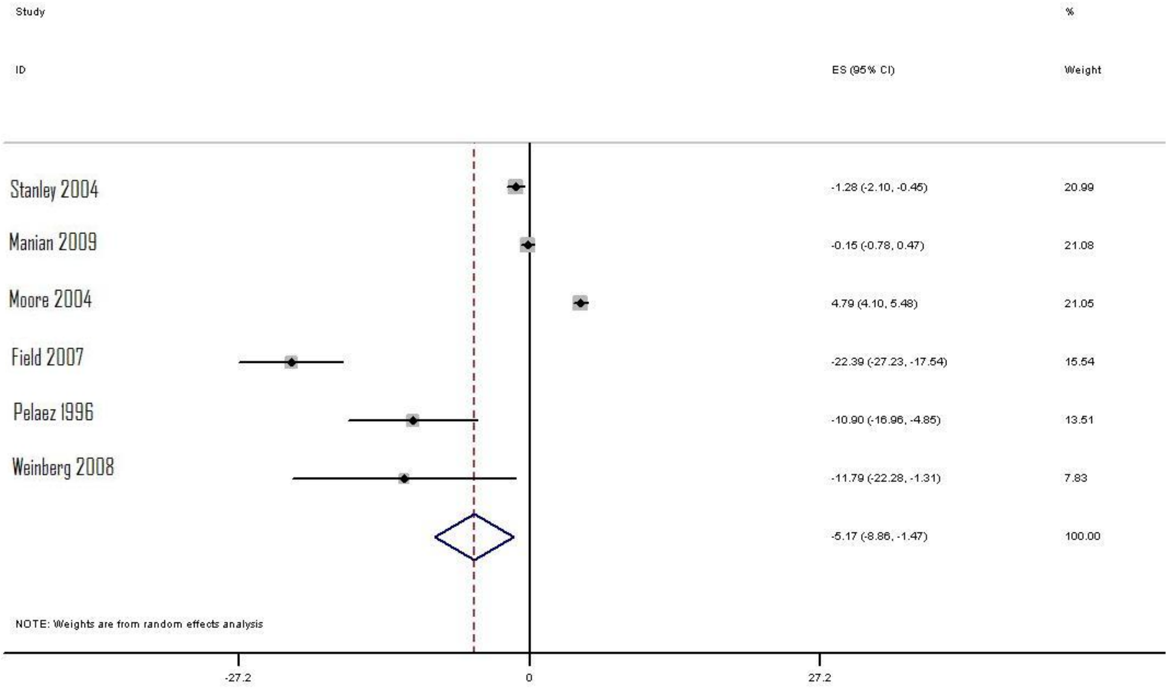

Figure 5.3. NA from baseline to still-face episode. A significant increase is seen for NA from baseline to the still-face episode by the confidence intervals of the overall PA being positioned to the left of the forest plot and not touching the solid vertical line of no effect (p<0.01).

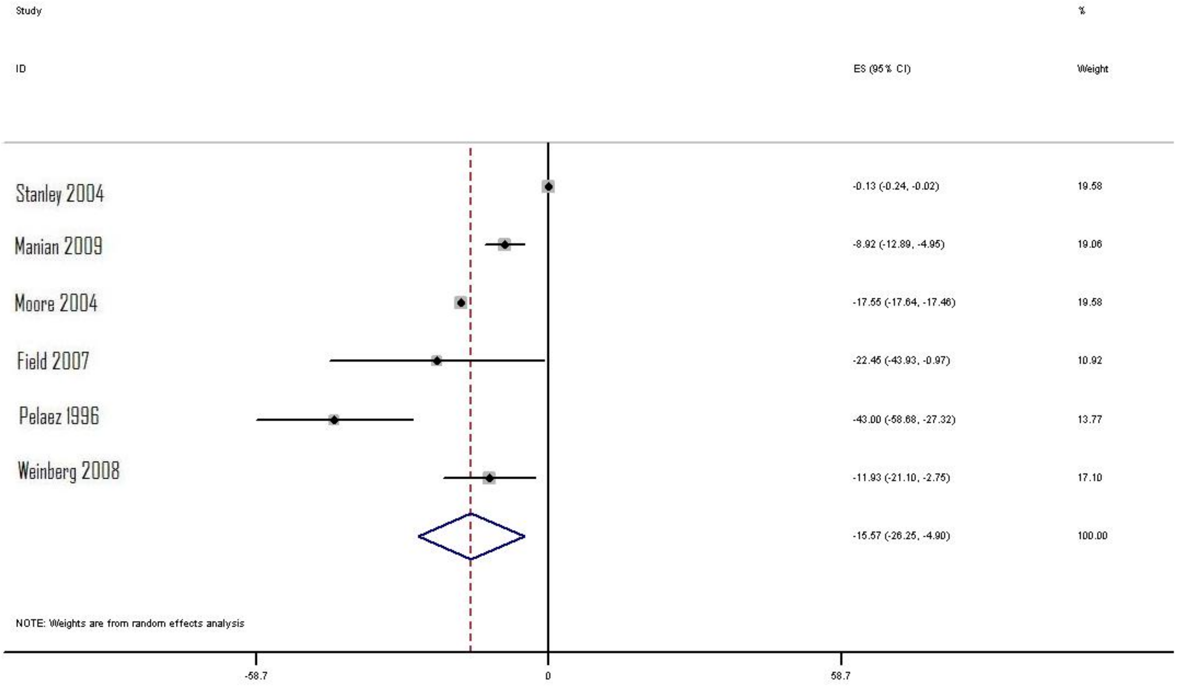

Figure 5.4. NA from baseline to still-face episode. A significant increase is seen in NA from baseline to the still-face episode by the confidence intervals of the overall PA being positioned to the left of the forest plot and not touching the solid vertical line of no effect (p<0.01).

In addition, negative affect was significantly higher at the reunion episode in comparison to the baseline episode (p<0.05) as shown in figure 6.5.

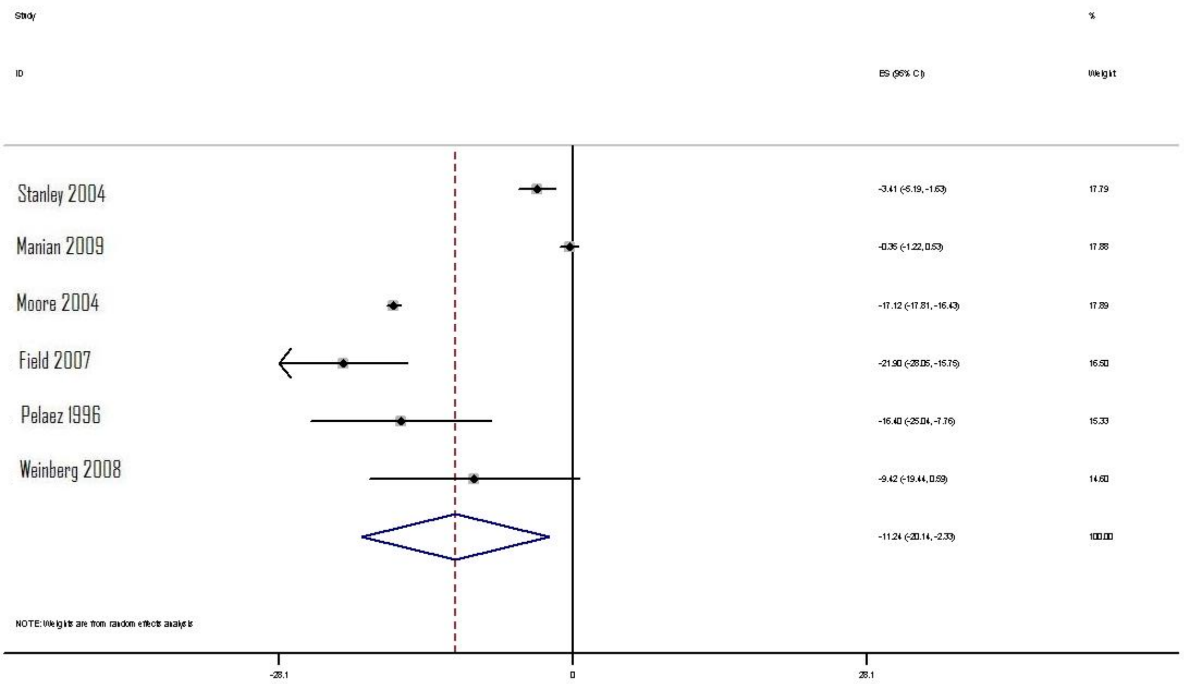

Figure 5.5. NA from baseline to reunion episode. A significant increase is seen for NA from the baseline to reunion episode by the confidence intervals of the overall NA being positioned to the left of the forest plot and not touching the solid vertical line of no effect (p<0.05).

5.4.2. Meta-Analysis 2

The second meta-analysis directly compared changes in PA, NA, and GA across each episode of the SFP between infants of depressed and non-depressed mothers. The purpose was to establish whether infants of depressed mothers display the classic SFE by comparing changes in PA, NA and GA through all the episodes of SFP to those of the non-depressed groups. No significant differences were found for changes in PA from the baseline to still-face episodes (p=0.84), still-face to reunion episodes (p=0.15) or baseline-to reunion episodes (p=0.33). There were also no significant differences in NA from the baseline to still-face episodes (p=0.97), still-face to reunion episodes (p=0.48) or baseline-to reunion episodes (p=0.09). Further to this, the groups did not differ significantly in changes in GA from the baseline to still-face episodes (p=0.87), still-face to reunion episodes (p=0.79) or baseline-to reunion episodes (p=0.28).

5.4.3. Meta-Analysis 3

The third meta-analysis directly compared infants of depressed and non-depressed mothers amount of behaviour (PA, NA, & GA) displayed at each stage. The aim was to see if levels of behaviour displayed by infants of depressed mothers differed from infants of non-depressed mothers for each episode of the SFP. The depressed group displayed significantly higher levels of PA during the still-face episode in comparison to the control group (p<0.01) as shown in figure 5.6.

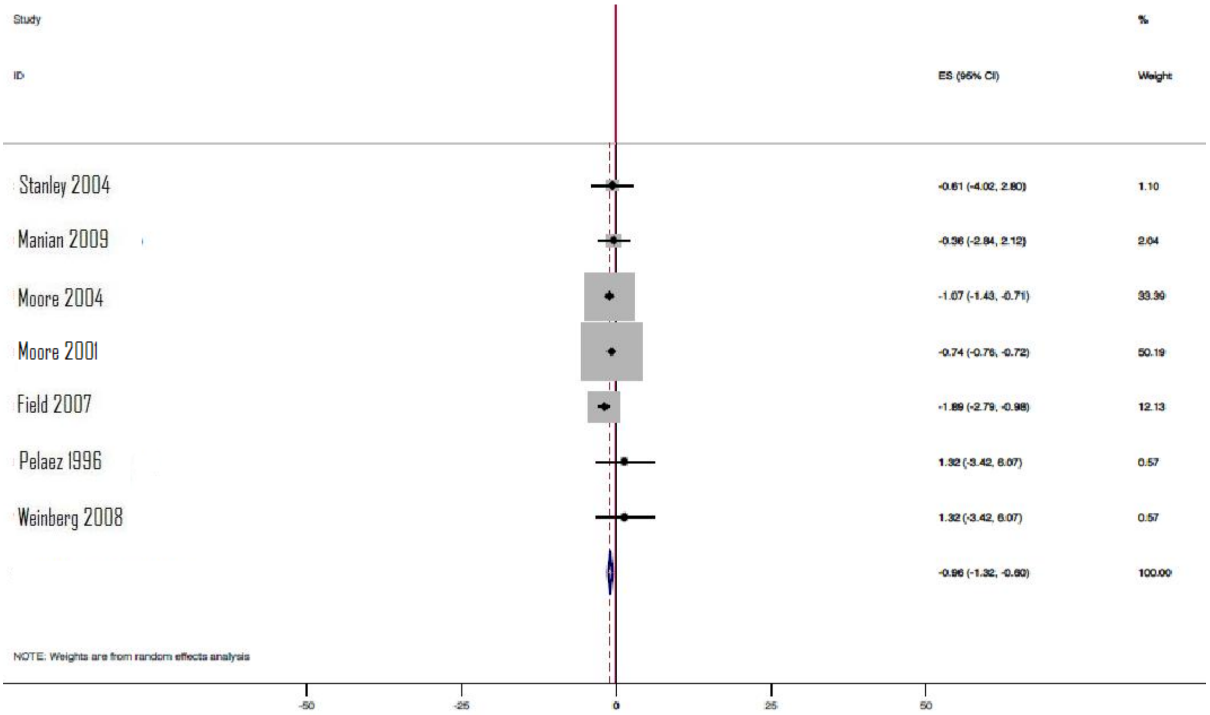

Figure 5.6. PA displayed at still-face episode. A significant increase is seen for PA at the still-face episode. This is shown by the confidence intervals of the overall PA being positioned to the left of the forest plot and not touching the solid vertical line of no effect (p<0.01).

PA did not differ significantly for the baseline (p=0.75) or reunion episodes (p=0.59). The infants of depressed mothers did not significantly differ from infants of non-depressed mothers for levels of NA displayed at the baseline (p=0.14), still-face (p=0.85) and reunion episodes (p=0.31). Similarly, no significant differences were revealed for GA during the baseline (p=0.39), still-face (p=0.79) and reunion episodes (p=0.79).

5.5. DISCUSSION

Within the current SFP literature, differing results have been reported regarding the behaviour of infants of depressed mothers in comparison to infants of non-depressed mothers. It was therefore deemed appropriate to conduct meta-analyses to further our understanding of atypical infant behaviour. The aims of this current study were to see if infants of depressed mothers demonstrate the classic still-face effect and if they display the same levels of PA, NA, and GA as their counterparts with non-depressed mothers.

As hypothesised, the initial meta-analysis confirmed the SFE in infants of non-depressed mothers. Because this effect was found, the depressed groups were then directly compared in the subsequent meta-analyses to see how behaviour differed between infants of depressed and non-depressed mothers. The second meta-analysis directly compared changes in PA, NA, and GA across each episode of the SFP between the depression and control groups. The purpose was to establish if infants of depressed mothers display the classic SFE by comparing changes in PA, NA and GA through all the episodes of SFP to those of the non-depressed groups. The results revealed that infants of depressed mothers did not differ from those of non-depressed mothers in the magnitude of changes in PA, NA and GA between stages of the SFP. In other words, infants of depressed mothers exhibit the classic still-face effect during the SFP. Just like infants of non-depressed mothers, the infants of depressed mothers demonstrated reduced positive affect from their baseline state, in addition to increased gaze aversion and negative affect, which continued into the reunion episode. This finding provides support for other studies which suggests that infants of depressed mothers find the SFP equally distressing as infants of non-depressed mothers (Stanley et al., 2004; Weinberg et al., 2008) and contradicts other studies stating the infants have increased/decreased GA (Manian & Bornstein 2009; Moore et al., 2001) or increased negative behaviours (Forbes et al., 2004; Rosenblum et al., 2002; Weinberg et al., 2006).

The third meta-analysis directly compared the depressed and control group for amount of behaviour (PA, NA, & GA) displayed at each stage. The aim was to see if levels of behaviour displayed by infants of depressed mothers differed from infants of non-depressed mothers during each episode of the SFP. Interestingly, and somewhat contradicting the results of the second meta-analysis, this meta-analysis showed that infants of depressed mothers had significantly greater PA during the still-face episode in comparison to their counterparts with non-depressed mothers. One possible explanation for the relatively higher PA could be, as Field (2002) has suggested, that infants of depressed mothers become accustomed to their mother's depressed behaviour and, therefore, are less distressed when their mother displays emotional disengagement towards them during the Still-Face episode. This finding initially provides support for previous studies which suggest that infants of depressed mothers find the SFP less distressing (Field, 2002; Field et al., 2007; Pelaez-Nogueras et al., 1996). However, the third meta-analysis also revealed that the depressed groups did not differ from the infants of non-depressed mothers on levels of NA. This indicates that the infants are finding the SFP as distressing as the non-depressed infants. One plausible explanation for the increase in PA in the third meta-analysis may be that infants of depressed mothers are adapting their behaviour to cope with their distress. Attachment theorists have found that an infant's response to their mother in any given situation is based upon previous experience and interactions with her (Ainsworth & Bowlby, 1991; Bretherton, 1992). Therefore, due to the infant's prior experience with their mothers disengaged behaviour they may be employing coping strategies during the still-face episode to cope with their distress, such as amplifying positive attachment signals in an attempt to engage maternal attention and support (Out et al., 2009). This viewpoint is supported by various authors who agree that infants of depressed mothers adopt coping strategies during the SFP (Field, 2002; Manian & Bornstein, 2009; Moore et al., 2001; Weinberg & Tronick, 1996). Field (2002) believes that infants of depressed mothers adopt passive coping strategies but these current meta-analyses did not reveal supporting evidence for this strategy. Infants did not produce a passive interaction style during the SFP and mirror their mother's depressive behaviour as Field suggests. Further to this, the current meta analyses did not reveal that infants of depressed mothers display an increase in GA or employ self-soothing techniques to cope with their distress as other authors have suggested (Manian & Bornstein, 2009; Moore et al., 2001).

The meta-analyses results did however provide support for Weinberg and Tronick's hypothesis (1996) which states that PA helps infants to down regulate feelings of distress. The authors speculate that PA is a coping strategy adopted by infants as it acts as a buffer against distress and NA. As greater PA was observed during the still-face episode in infants of depressed mothers, this could be indicative of these infants adopting this strategy as a way of coping with the stress induced by the SFP. Additionally, increased PA when infants are interacting with their depressed mothers during the SFP has been found by other authors (Field, 2002; Pelaez-Nogueras et al., 19960).

The current study provides a useful addition to the still-face literature, demonstrating differences between infants of depressed and non-depressed mothers behaviour. However, it can only provide an insight into how infants of depressed mothers react in the SFP towards their mother. The study does not address whether the behaviour observed in infants is continuous with other caregivers and strangers. As attachment theorists (Ainsworth & Bowlby, 1991; Bretherton, 1992) have noted, an infant's reaction to a caregiver is based on the quality of interactions the infant has experienced with that particular individual. Infants of depressed mothers may become accustomed to their mothers depressed behaviour as Field (2002) suggests and react in a way they deem appropriate with her (i.e. adopting increased PA either as a coping strategy to reduce distress from previous experience of disengaged interactions or to better engage support from their depressed parent). A future direction for this research could be to investigate whether behaviour observed during the SFP in infants of depressed mothers is true when infants are interacting with other individuals. For example, do infants of depressed mothers still display greater PA than infants of non-depressed mothers when interacting with individuals with whom they have no prior experience, or with other caregivers who do not have a depressed interaction style? It is possible that the observed difference in PA may only be evident in interaction with their mothers. If this were true it would suggest that infants of depressed mothers are able to detect a depressed interaction style and are adapting their behaviour accordingly as Out et al. (2009) suggests as a way of reengaging, or as Weinberg and Tronick (1996) suggest as a way of coping with the withdrawn behaviour displayed by their mother.

Despite the current findings, it is important to note that data from only seven studies were included out of a possible eleven. This was due to data no longer being available and from authors refusing to share their data. Inclusion of all studies would be beneficial in a future meta-analysis to ensure findings from the current study are replicated and representative of the whole SFP depression literature.

In summary, infants of depressed mothers do become distressed during the SFP. This was evident from the infants displaying the classic still-face effect like their non-depressed counterparts. However, the infants of depressed mothers demonstrate significantly higher levels of PA during the still-face episode. Potential interpretations of these findings is that due to their prior experience of similar, depressed interactions with their mothers, the infants of depressed mothers amplify their positive attachment signals to engage maternal attention and response or are using PA in order to regulate their NA. A future direction would be to conduct studies with other caregivers and with individuals of which the infant has no prior experience. This would investigate whether the amplified PA is only employed with their depressed mothers or whether it is a generalised response towards all individuals.

CHAPTER 6

GENERAL DISCUSSION

6.1. Thesis aims and overview

This thesis had three main aims. Firstly, to explore the experience of auditory and visual social and non-social stimuli upon infants brain functioning. Secondly, to explore the role of the prefrontal cortex (PFC) in social and non-social visual processing and anxiety. Lastly, to investigate the effect of a mother's depression upon infant behaviour. The thesis began with an overview of the relevant literature in Chapter 1. Chapter 2 moved on to explore the EEG methodologies, ethical considerations and procedures used within the current thesis. As little is currently known about the neural mechanisms which underlie speech processing (Dehaene-Lambertz, Dehaene & Hertz-Pannier, 2002; Vouloumanos & Werker, 2007), Chapter 3 sought to examine the time-course and neural mechanisms involved in the processing of speech versus non-speech. A match-mismatch experimental design was employed to avoid the limitations of oddball designs, which are commonly used to explore speech and non-speech processing (see Chapter 3 section 3.2 for further information on oddball limitations). After examining speech and non-speech processing in the auditory domain in infancy, chapter 4 moved on to explore social and non-social processing in the visual domain in infancy. The chapter was comprised of two parts. Part one investigated the impact of social and non-social stimuli upon frontal brain activation in infants. Frontal EEG asymmetries can be indicative of social behaviour in infancy (Coan & Allen, 2003; Davidson, Ekman, Saron, Senulis & Friesen, 1990; Dawson, 1994; Field & Diego, 2008; LoBue, Coan, Thrasher & DeLoache, 2011; Mundy, Card & Fox, 2000). Resting state EEG is regularly measured from the PFC whilst infants experience social and non-social stimuli, however, little is known about the impact of these stimuli upon frontal EEG asymmetries (Green & Zadiel, 2011). Therefore, a social and non-social paradigm was designed in chapter 4, part one, to compare the impact of these stimuli upon infant frontal asymmetries. Part two of chapter 4 moved on to explore infant frontal asymmetries and emotion based disorders. Differences in frontal EEG asymmetries are seen as a predictor of risk for a variety of emotion based disorders (Fingelkurts et al., 2007), with greater right frontal brain activation being coupled with depression and anxiety in adults (Beaton et al., 2008; Henriques & Davidson, 1991). Furthermore, infants of depressed mothers have also been found to show greater right frontal activation (Dawson, Frey, Panagiotides, Osterling, & Hessi, 1997; Diego, Field, Jones & Hernandez-Reif, 2006; Field & Diego, 2008; Jones, Field, & Almeida, 2009). Frontal asymmetry patterns in infants of anxious mothers, however, has not been investigated. The aim of chapter 4, part two, was to examine the relationship between infant frontal EEG asymmetries and mother's maternal anxiety. Infant EEG data collected in part one from the social and non-social paradigm was compared to maternal scores of anxiety. This allowed for further examination of the social and non-social paradigm, to see if the social condition would allow for a reliable measure of resting infant EEG, in addition to examining the relationship between infant EEG and maternal anxiety. After exploring the effects of maternal anxiety on infant brain functioning, it was deemed necessary to also review how infant behaviour can also differ as a result of having a mother with an emotion based disorder. The behavioural impact upon infant behaviour will enable researchers to make links between brain and behaviour within emotion based disorders. Evidence has shown that infants of mothers with depression and anxiety will show behavioural differences when compared to infants of mothers without these disorders (Cohn, Campbell, Matias, & Hopkins 1990; Field, Healy, Goldstein, & Guthertz, 1990; Diego et al., 2006; see Chapter 1 section 1.4. for further information). Despite reported differences in infant behaviour being found it is not fully understood what behaviours are standardly found (Mesman et al., 2009). Behavioural research regarding infants of anxious mothers is limited, with existing studies relying upon different methodologies. However, within the depression literature, numerous studies have employed the same paradigm to measure mother-infant interaction, the Still-Face Paradigm (SFP: Tronick, Als, Adamson, Wise & Brazelton, 1987). Therefore, for chapter 6, a meta-analysis was performed to provide an objective and informative overview of behaviour displayed by infants of depressed mothers during the SFP.

This final chapter will begin by summarising the findings of each chapter. After findings and interpretations of these findings have been discussed, the integration of results within the previous context and literature will be considered. This chapter will then move onto provide suggestions for future directions for the research, alongside a discussion of the implications of each chapter's results. The general discussion will then move on to discuss the main limitations of the current thesis followed by a brief conclusion.

6.2. Summary and interpretations of findings

The findings of each chapter will now be summarised and interpretations of the results will be discussed.

6.2.1. Chapter 3

Chapter 3 (speech and non-speech processing in infants) explored the time-course and neural mechanisms involved in the processing of speech versus non-speech stimulus categories in infancy. The results of the current study provided evidence for the specialisation of the left hemisphere during speech processing , as a mismatch effect was found in infants frontal central regions and the temporal regions. Additionally, the left-frontal-central region was found to have an early perceptual role followed by a later higher level cognitive role of speech processing during the speech mismatch condition. The left-temporal region however was only implicated in the cognitive evaluation of stimuli during the speech mismatch condition. This suggests that both regions are specialised for language processing, with the temporal region playing a role in the later interpretation of speech stimuli and not the initial differentiation of the categories. Despite the close nature of the speech and non-speech stimuli, infant brain responses in the speech mismatch conditions strongly suggest that infants are able to discriminate between the categories. The findings of the current study suggest sophisticated neural network for speech processing exists from early infancy.

6.2.2. Chapter 4 Part 1

Chapter 4 part 1 (social and non-social processing in infancy) investigated the role of social and non-social stimuli upon infant frontal asymmetries. The main and novel finding of the current study was that female infants showed greater right frontal brain activation during the non-social condition than the social condition. Male infants did not show hemispheric differences for either condition. The greater right frontal activation in the non-social condition was interpreted as the female infants having a negative response to the non-social stimuli and therefore a greater behavioural preference for the social condition. This finding is unique in that it provides neurobiological evidence for differences in social preferences between male and female infants. The second main finding of this study was that across male and female infants, greater left frontal activation was coupled with the social condition. This finding indicated that infant brain functioning was influenced by the social experience of the condition.

6.2.3. Chapter 4 Part 2

Chapter 4 part 2 (the effect of mothers anxiety symptoms upon infant brain functioning) examined the effect of maternal anxiety symptoms upon infant brain functioning. In this non-clinical sample, mothers' trait anxiety was not found to be predictive of infant frontal EEG asymmetry profiles. Anxiety symptoms were also not predictive of frontal EEG asymmetry when age and gender of the infants were included as potential modifying factors. This finding is useful in providing preliminary evidence to suggest that normal to moderate levels of anxiety symptoms within a typical community sample do not significantly or negatively affect infant brain functioning.

6.2.4. Chapter 5

Chapter 5 (meta-analysis: depression and the still-face paradigm) compared the behaviour of infants of depressed mothers to infants of non-depressed mothers during the still-face paradigm (SFP). The aim of this study was to see if infants of depressed mothers demonstrate the classic still-face effect and if they display the same levels of Positive Affect (PA), Negative Affect (NA), and Gaze Aversion (GA) as their counterparts with non-depressed mothers. Results revealed that infants of depressed mothers display the classic still-face effect, like infants of their non-depressed counterparts. However, the infants of depressed mothers also demonstrated significantly higher levels of PA during the still-face episode than infants of non-depressed mothers. Potential interpretations of these findings are that due to their prior experience of similar, depressed interactions with their mothers, the infants of depressed mothers amplify their positive attachment signals to engage maternal attention and response, or are using PA in order to regulate their NA.

6.3. Integration with previous context

The integration of each chapter's findings with previous literature will now be considered. For example, how do the findings of the current thesis provide support for, contradict or add to the current literature.

6.3.1. Chapter 3

The results of chapter 3 provided evidence for the specialisation of the left hemisphere during speech processing as opposed to a left lateralisation effect. This result provides support for Kotilahti and colleagues (2010) who did not find left lateralisation in infants for speech but a significant effect in the left hemisphere in response to speech. This result suggests a sophisticated neural network for speech processing which exists from early infancy but is still developing.

Despite support for this result, this finding also contradicts early research which has found left-lateralisation (Dehaene-Lambertz, 2000; Dehaene-Lambertz et al., 2002), bilateral activation (Dehaene-Lambertz et al., 2006) and no lateralisation effects (Dehaene-Lambertz & Baillet, 1998; Pang et al., 1998) in response to speech. Differences in results could be due to a variety of reasons such as differences in neuroimaging techniques employed and differences in experimental designs. Firstly, the current study relied upon EEG to measure infant brain activation in response to speech and non-speech, whereas other studies have relied upon fMRI (Dehaene-Lambertz et al., 2002; Dehaene-Lambertz et al., 2006). EEG and fMRI methodologies have their contrasting strengths and weaknesses, for example fMRI has far superior spatial resolution and EEG has advanced temporal resolution (Neil, 2006). However, this explanation is not satisfactory, as it does not explain why differences are apparent within the same methodologies. For example, even techniques using EEG have found differing results, Pang et al. (1998) and Dehaene-Lambertz and Baillet (1998) did not find lateralisation effects for speech in comparison to Dehaene-Lambertz (2000) who found a left lateralisation effect for speech. A potential explanation for differences could be the differences in experimental designs between studies. Some studies did not use a control condition to non-speech (Dehaene-Lambertz et al., 2002; Dehaene-Lambertz et al., 2006), however, the current study did. The results from the current study suggest that the left-frontal-central region was found to have an early perceptual role followed by a later higher level cognitive role of speech processing during the speech mismatch condition. The left-temporal region however was only implicated in the cognitive evaluation of stimuli during the speech mismatch condition. Due to the role of each region, it is possible that these effects were seen in response to differentiating between speech and non-speech stimuli which previous studies did not allow for (for example: Dehaene-Lambertz et al., 2002; Dehaene-Lambertz et al., 2006). Furthermore, previous EEG studies have relied upon oddball experimental designs. This leaves open the possibility that differences in brain responses may be a result of attentional brain mechanisms, which as a result, would not have been present in the current study due to the match-mismatch design employed.

Although contradictory results have been found in terms of lateralisation (Dehaene-Lambertz, 2000; Dehaene-Lambertz & Baillet, 1998; Dehaene-Lambertz et al., 2002; Dehaene-Lambertz et al., 2006; Pang et al., 1998), the regions implicated in speech processing in infancy are similar. For instance, the current study found the left-temporal and left-frontal-central regions to play a role in speech processing. Other studies have also found effects for the frontal and temporal regions (Dehaene-Lambertz et al., 2002; Dehaene-Lambertz & Baillet, 1998; Dehaene-Lambertz et al., 2006; Minagawa-Kawai et al., 2010; Pang et al., 1998) during speech processing. Furthermore, as in the current study, Pang et al. (1998) specifically found the T3 and C3 regions to play a role in speech processing in infancy. As previously discussed, differences in lateralisation in these regions may be a result of different methodologies and experimental designs. However, the current results suggest that infants are developing specialisation in the brain for speech processing, so lateralisation in these regions may not have emerged yet.

6.3.2. Chapter 4 Part 1

Greater left frontal activation was found in the social condition. This result supports previous research which suggests that the PFC plays a critical role in social cognition (Cpan & Allen, 2003; Davidson et al., 1990). For instance, previous research has found greater left frontal activation for social approach (Dawson, 1994; Davidson et al., 1990; Field & Diego, 2008; Hane et al., 2008; Henderson & Marshall, 2008) and the ability to initiate joint attention with a partner (Mundy et al., 2000). This result therefore suggests, in line with previous research, that the social nature of the stimuli in the social condition resulted in greater left frontal activation in infants. However, it is important to note, that previous research has also suggested that frontal asymmetry patterns can differ as a result of the emotions elicited by stimuli observed (Davidson et al., 1990). For example, if an infant is watching something which is positively engaging to them, this could also result in greater left frontal activation. The social stimuli created were positive compared to a neutral non-social condition. Therefore, despite previous research supporting the current finding of the social condition influencing infant asymmetry, it is also possible that the emotions elicited as a result of the stimuli may well be contributing to the asymmetry differences seen between conditions.

The second main finding of the current study was that female infants displayed greater right frontal activation in response to the non-social stimuli in comparison to males who did not show a preference for either condition. At first glance, this result appears to contradict previous behavioural literature which has described female infants as socially superior as they have shown preferences for social stimuli (Connellan et al., 2000; Lutchmaya et al., 2002) and males showing preferences for non-social stimuli (Connellan et al., 2000; Lutchmaya & Baron-Cohen, 2002; Lutchmaya et al., 2002). As the current study did not use any behavioural measures of infant preference, preferences between conditions could only be interpreted from the neurophysiological data obtained and previous behavioural studies. As females showed a significant negative and withdrawn brain response to the non-social condition, it is highly likely that this response would be reflected in their behaviour for this condition. Therefore, this is indicative that females would have a behavioural preference for the social condition over the non-social condition. In addition, as the males did not show a difference in brain functioning for either condition this would mean they are not displaying a withdrawn or negative behavioural reaction to this condition. It is therefore possible that this would appear as the males having a non-social preference when compared to the female group as they would not be showing an avoidant reaction where the females would. Therefore, when considering the behavioural presentation of frontal asymmetries, the current results provide supporting neurobiological evidence for previous studies which have found females to have a preference for social stimuli (Connellan et al., 2000; Lutchmaya & Baron-Cohen, 2002; Lutchmaya, Baron-Cohen & Raggatt, 2002).

The current study also provided support for previous research examining maternal well-being and infant frontal asymmetries. Greater left activation was found overall for the whole sample, this finding was expected as all mothers who participated were psychologically well. Previous literature has found maternal psychological well-being to be associated with greater left frontal brain activation in infants (Davidson, 2004).

The final finding of the current study was the DLPFC displaying greater overall brain activation in comparison to the OFC. Greater activation was interpreted as the DLPFC representing the attentional demands of the current study and the processing of the information held within the infants' working memory as this is supports what previous authors have suggest (Golkar et al., 2012; Wallis & Miller, 2003). Furthermore, despite the DLPFC having greater activation overall, the OFC was found to display a pattern of activation similar to that of the DLPFC. This finding supports previous studies (Golkar, 2012; Kawasaki et al., 2001) the authors have suggested that the OFC and DLPFC have similar processing roles within social cognition.

6.3.3. Chapter 4 Part 2

As previously discussed, anxiety and depression are highly co-morbid (Kaitz et al., 2010) and adults with these disorders typically show greater right frontal brain activation (Beaton et al., 2008; Henriques & Davidson, 1991). It was expected that infants of mothers with higher anxiety levels would exhibit greater right frontal brain activation as this pattern is seen in infants of depressed mothers (Dawson et al., 1997; Diego et al., 2006; Field & Diego, 2008; Jones et al., 2009). However, maternal anxiety levels did not predict infant frontal asymmetry patterns in the current study. There are various possibilities as to why this was not found within the current study. Firstly, mothers who participated in this study did not have a history of depression or anxiety in addition to not suffering from these disorders at the time of participation. As a result, mothers who participated only reported as a maximum, moderate anxiety. In studies where frontal asymmetry patterns were explored in infants of depressed mothers, the participating women all met criteria for depression. Therefore, as mothers were recruited from a community sample and did not meet criteria for an anxiety disorder, the current study was not representative of maternal anxiety on a whole. Furthermore, predictions based on maternal anxiety and infant frontal asymmetries were based on previous studies within the depression literature. Although anxiety and depression commonly co-occur (Kaitz et al., 2010), depression and anxiety are different disorders, furthermore, the interaction between the two is not fully understood (Kaitz et al., 2010). Therefore, it is possible that maternal anxiety traits were not reflected in infant frontal asymmetries, as anxiety may not affect infant physiology in the same way that depression does.

6.3.4. Chapter 5

The current meta-analysis confirmed that infants of depressed mothers display the classic still-face effect (SFE). This result provides support for previous studies which suggest that infants of depressed mothers find the still-face paradigm (SFP) equally as depressing as infants of non-depressed mothers (Moore and Calkins, 2004; Stanley et al., 2004; Weinberg, Beeghly, Olson and Tronick, 2008). Furthermore, this finding does not support previous findings which suggest that infants of depressed mothers display fewer negative behaviours

(Field, 2002; Field et al., 2007) or increased negative behaviours (Forbes, Cohn, Allen, & Lewinsohn, 2004; Rosenblum et al., 2002; Weinberg et al., 2006).

The results of the meta-analyses also revealed that infants of depressed mothers displayed significantly more positive affect during the still-face episode. A similar result was reported by Pelaez-Noguras, Field, Hossain and Pickens (1996). The authors interpreted this finding as infants of depressed mothers being less distressed during the SFP as infants would be accustomed to their mothers disengaged behaviour. However, as the results of the current study show that infants of depressed mothers display the classic SFE, it is evident that the infants of depressed mothers are finding the experience equally as distressing as their non-depressed counterparts. Instead, the increased positive affect seen during the still-face episode could be an indication of the infants adopting coping strategies. For instance, research has suggested that infants of depressed mothers develop passive coping styles due to repeated exposure to depressed interactions with their mothers (Field, 2002). Further research on maternal psychopathology has also suggested that infants will attempt to minimise the expression of negative emotions in order to deal with stressful circumstances and to encourage maternal attention (Out et al., 2009). Weinberg and Tronick (1996) believe that infants of depressed mothers use positive affect (PA) as a way of coping with the SFP, by down-regulating the feelings of distress that it induces. Therefore the current results suggest that infants of depressed mothers do find the SFP equally as distressing as their non-depressed counterparts and use positive affect in order to regulate their negative affect or are amplifying their positive attachment signals in order to attract maternal attention.

6.4. Implications of results and future directions

The results of this thesis have many implications for the current field and for future directions in this area of research. Implications and directions for future work will be discussed below in the context of the relevant chapter.

6.4.1. Chapter 3: Speech and non-speech processing in infants

The current literature revolving around early speech processing is limited, with little being known about the neural mechanisms which underlie speech processing in infancy (Dehaene-Lambertz, et al., 2002; Vouloumanos & Werker, 2007). The major implication of this chapter is that it has provided an insight into the neural processes underlying speech and non-speech processing in infancy. Infants were not found to have left lateralisation for speech processing as adults do (Dronkers et al., 2004; Hickok & Poeppel, 2007; Keller et al., 2009; Price, 2010), however, the left temporal and left-central-frontal regions were found to be differentiating between speech and non-speech, implying the specialisation of these regions in language processing in infancy. Furthermore, the left-frontal central area was found to be involved in early perception and later evaluation of speech and the left temporal region just in the cognitive evaluation of the speech stimuli. These results therefore illustrate the early neural mechanisms underlying speech processing, specifically the importance of the left hemisphere in language processing from infancy. This finding has major implications for this area of research as it provides an invaluable insight into the development of speech processing in the brain. Future directions with this work would be to further explore the development of neural mechanisms which underlie speech processing in older infants, children and adults to understand the development of language processing in the brain throughout the lifespan. As a result of further work, it would be possible to create an understanding of the typical development of language processing in the brain. If details were taken of individuals who later developed disorders of language, for example dyslexia, it would be possible to look at brain functioning at various stages in life (for example, infancy, childhood and adolescence). This would allow researchers the possibility to see if any differences in brain functioning exist for individuals who later develop language disorders. This could aid in the early detection of language disorders and perhaps would allow for earlier intervention to aid the individual.

6.4.2. Chapter 4 Part 1: Social and non-social processing in infancy

The results of chapter 4 represent a major implication for researchers who have measured frontal asymmetries in infants by using social and non-social stimuli to obtain resting state EEG. Firstly, as female infants showed greater right frontal brain activation during the non-social condition and male infants did not show hemispheric differences for either condition, this demonstrates that gender differences do exist between conditions and need to be taken into consideration when obtaining resting EEG. Further to this, overall greater left frontal brain activation was seen for both male and female infants for the social condition implying that the social nature of the stimuli affected their frontal activation pattern. This finding has implications for previous studies which have relied upon social (Fox et al., 2001; Hane, Fox, Henderson & Marshall, 2008) methods when obtaining resting EEG. Researchers wishing to obtain resting EEG from infants should not rely solely on a social measure. Infant frontal asymmetries are influenced by the social nature of the stimuli and differences may occur as a result of the gender of the infant, meaning that a true representation of the resting state in the brain has not been achieved. A future direction for this research would involve assessing the extent to which social stimuli affect infant frontal asymmetries. For example, creating a study whereby infants are exposed to positive, negative and neutral social stimuli. This would establish whether the greater left frontal activation found in the social condition is a result of the social nature of the experience per se, or a result of the infants demonstrating a positive reaction in response to the positive nature of the condition. A result of this further research would be to increase researchers understanding of the impact of social stimuli and experiences upon infant brain functioning. This would give researchers the potential to create an appropriate paradigm that would be a reliable measure of baseline EEG. As resting frontal EEG asymmetries are commonly used to measure various personality traits such as joint attention, temperament and social approach and even risk for emotion based disorders (see chapter 4 part one, section 4.2 for further information), this developed paradigm would provide a reliable and standardised measurement for use within this field.

6.4.3. Chapter 4 Part 2: The effect of mothers anxiety symptoms upon infant brain functioning

In chapter 4 part 2, mothers' trait anxiety was not found to be predictive of infant frontal EEG asymmetry profiles even when age and gender of the infants were included as potential modifying factors. This finding has positive implications which suggest that normal to moderate levels of anxiety symptoms within a typical community sample do not significantly or negatively affect infant brain functioning. However, as demonstrated by the current literature, maternal anxiety does affect maternal behaviour (Kaitz et al., 2010; Harper et al., 2007; Feldman et al., 1997), which in turn has an impact upon infant behaviour (Blissett et al., 2007; Stifter et al., 1993; Kaitz et al., 2010). Further work is needed in order to explore the effect of maternal anxiety on infant brain functioning to a greater extent. This would involve including an enriched sample of mothers who meet criteria for a clinical diagnosis of an anxiety disorder. Additionally, as there are many types of anxiety disorder, such as generalised anxiety disorder, social phobia and obsessive compulsive disorder (APA, 2013), it would be beneficial to look at each anxiety disorder individually to determine similarities and differences in the collected infant neurophysiological data. This would be beneficial in allowing researchers to obtain a greater understanding of impact of different anxiety disorders in the infant brain. Furthermore, if certain disorders have a greater impact on infant brain functioning, this could be an indication of possible high-risk groups who would benefit from intervention. As a result, this further research could impact on intervention services offered in cases of maternal anxiety in an effort to encourage more typical mother-infant interactions styles.

An additional future direction for this research would be to include a depressed subset. As depression commonly co-occurs with anxiety (Kaitz, Maytal, Devor, Bergman, & Mankuta, 2010) and a mothers depression has been shown to affect their infants' brain functioning (Dawson et al., 1997; Diego et al., 2006; Field & Diego, 2008; Jones et al., 2009) it would have been beneficial to see if depression symptoms would have impacted this studies results. Furthermore, to compare infant brain functioning between anxiety and depression groups to see if differences emerge, in addition to comparing infant brain functioning to a subset of co-morbid anxiety and depression participants. This would allow researchers to understand the neurophysiological presentation of these disorders to a greater degree, to see if one disorder ultimately drives the differences and therefore has greater impact on infant brain functioning and perhaps behaviour. The implication of this further research would be possible identification of whether both disorders or one in isolation leads to a higher risk of impact upon infant brain functioning. This could indicate which groups of individuals would benefit from early behavioural interventions, for example, research has shown that infants of depressed mothers can display typical behaviours depending on the type of interaction the mother displays (Field, Diego, Hernandez-Reif, Schanberg & Kuhn, 2003). Research on mother-infant interactions and this further research could result in effective interventions, centred on infant behaviour, leading to positive behaviour outcomes in later life.

6.4.4. Chapter 6: Meta-analysis: depression and the still-face paradigm

The finding that infants of depressed mothers demonstrated significantly higher levels of PA during the still-face episode than infants of non-depressed mothers provided further evidence that a mother's depression does affect her infant's behaviour. This finding has several implications in terms of the questions in raises. For instance, 1) is the difference in infant behaviour a result of the depressed interaction style with their mother and seen with her alone, or is it replicated with other caregivers. Additionally, 2) are the differences in behaviour a reflection of differences in infant brain functioning as a result of having a depressed mother, as greater right frontal brain activation has been consistently found in infants of depressed mothers (Beaton et al., 2008; Dawson et al., 1997; Henriques & Davidson, 1991). This study has pinpointed some of the behavioural differences that exist in infants of depressed mothers. However, future research is needed to begin to understand and explore why this behaviour is occurring, if the behaviour only occurs exclusively with the mother and what effect it has upon the infant (if any) in the long-term. Additional implications of these results relate to improving mother-infant interactions, because infants of depressed mothers are shown to be equally distressed during the SFP and display coping strategies in order to regulate their negative affect or to engage in maternal contact. Behavioural differences seen in infants of depressed mothers continue into childhood and adolescence, impacting personality, social interactions and physical activity (Bernanrd-Bonnin, 2004). Interventions tailored specifically to increasing maternal sensitivity and engagement could be created to increase typical interactions between mother and infant. For instance, Field et al (2003) found that depressed mothers with good interaction styles in comparison to withdrawn or intrusive interaction styles had infants who displayed more typical behaviours. Increasing typical behaviours earlier on could potentially have a positive impact on later behaviours.

6.5. Limitations

This chapter will now discuss the limitations of the current thesis which will include the limitations of EEG, limitations of the sample, lack of behavioural data, statistical limitations, the utility of the Hospital Anxiety and Depression Scale (HADS) and representativeness of maternal psychopathology in the current sample.

Firstly, EEG was an extremely useful and suitable tool for this thesis as it was suitable for infants and allowed us to explore the localisations of processes in the brain in response to social and non-social stimuli in addition to mapping the time-course of brain responses in chapter 3. However, this EEG methodology also represents a major limitation of this thesis in terms of fully identifying the neural areas involved. Due to the manner of EEG, the measurements obtained only reflect the surface measurements of activity, which is a result of activity from many different sources in the brain (Kushnerenko et al., 2002). Although the EEG measurement tells us where activation is seen on the scalp, this scalp location can give a misleading impression as to the location of the source of the activity and in fact tells us very little about the area of the brain which actually generated the activation. Therefore, it is possible that activation seen in the frontal lobes may be a direct result of activation in another area, for example a rebound of activation in the temporal lobes (Kushnerenko et al., 2002). This however, is a common limitation within EEG and one which has a solution (Davidson, 2004; Kushnerko, et al., 2002). A method called source analysis can be used on the collected EEG data to determine the underlying brain areas responsible for the scalp activations (Davidson, 2004). Source analysis could be applied to the EEG data collected in this thesis to pinpoint sub-cortical regions in the brain responsible for the scalp activations (Davidson, 2004).

There are several limitations relating to the representative nature of the sample who participated in this thesis in terms of women who participated, particularly with regard to their social economic status (SES) and lack of maternal anxiety. Firstly, individuals who took part had to be committed and motivated as they had to make the effort to visit The University of Birmingham with their infant. Therefore, it is possible that the sample consisted of mothers who had more outgoing and relaxed personality traits. Differences in frontal EEG asymmetries are linked to differences in trait tendencies within individuals in areas such as approach or withdrawal behaviours (Coan & Allen, 2003; Davidson et al, 1990). It is therefore possible that the results in chapter 4, part 1 and part 2, reflected typical brain functioning for individual's with approach personalities, and not of the overall general population. To control for this in future studies, it would be beneficial to have mothers of infants complete a measure such as the Behavioral Inhibition Scales (BIS) and Behavioral Activation Scales (BAS: Carver & White, 1994). This would improve the representation of people who display approach and withdrawn personalities. Additionally, it would allow us to see if group differences exist between personality type which impact upon brain functioning in the social and non-social conditions.

A second limitation relating the representative nature of the sample, was the social economic status (SES) of the participants. Mothers who participated were all from middle class backgrounds, therefore the overall sample was not representative of individuals who come from areas with high socioeconomic deprivation. SES has been shown to affect structural and functional brain development in childhood but research on the effects in infancy is limited (Tomalski, Moorem Ribeiro, Axelsson, Murphy, Karmiloff-Smith, et al., 2013). Despite the limited literature, a recent EEG study conducted by Tomalski and colleagues (2013) found lower frontal gamma power in 6- to 9-month-old infants from low-income homes. The results suggest that SES can result in brain activation differences in infancy. Therefore, future research in this area should make every effort to incorporate participants from different SES backgrounds to ensure generalisability of results.

A final limitation, related specifically to the sample in chapter 4 was the low levels of maternal anxiety. As a community based sample participated, the highest degree of anxiety reported was moderate. As a result, the study did not have a sample which reached clinical levels of anxiety, so the study at best was a comparison of maternal anxiety traits to infant brain functioning. This made the results difficult to compare to the existing depression literature which included samples of women who reached clinical diagnosis for depression. The full implications of this limitation are discussed in detail in chapter 4 part 2, section 4.2.5. This limitation also highlights another weakness of this study, the measure used to assess levels of maternal anxiety, the HADS (Zigmond & Snaith, 1983). Chapter 4, part 2 administered the HADS to measure the severity and prevalence of maternal anxiety symptoms within the current sample. This measure was chosen as numerous authors have reported the reliability of the HADS in assessing symptom severity of anxiety within the general population as well as in psychiatric settings (Bjelland, Dahl, Haug, & Neckelmann, 2002; McDowell, 2006). The HADS has been criticised for its simplicity as it aims to categorise levels of anxiety and depression from fourteen items and it is believed by some to only measure levels of generalised distress (Coyne & Sonderen, 2012). However, given that the HADS is well established, convenient, fast to administer and has equally good sensitivity as other commonly used self-rating measures (Herrmann, 1997; Bjelland et al., 2002) it was deemed appropriate for the current study. Despite being deemed an appropriate measure at the time of the study, the HADS is a simplistic measure and does not take into consideration various types of anxiety disorders. There are a range of anxiety disorders, including Generalised Anxiety Disorder (GAD) which is excessive anxiety or worry about general occurrences in everyday life; Social Phobia, excessive anxiety associated with public embarrassment; Post Traumatic Stress Disorder (PTSD), feelings of anxiety revolving around a past traumatic event; Panic Disorder, panic attacks from excessive anxiety; and Obsessive Compulsive Disorder (OCD), compulsions and obsessions which dramatically affect every day functioning for the individual (American Psychiatric Association, 2013). Therefore, the use of the HADS may have been too broad of a measure of anxiety as it does not account for specific types of anxiety disorders, for example, items on the HADS may not account for the range of symptoms seen within differing anxiety disorders. It may have been beneficial to have included a more specific measure of anxiety disorders for instance The Psychiatric Diagnostic Screening Questionnaire (PDSQ: Zimmerman and Mattia, 1999). Although the PDSQ is more time consuming to complete, it covers a range of anxiety disorders, is widely used in outpatient mental health and has excellent levels of reliability and concurrent validity (Zimmerman & Mattia, 2001). The PDSQ would also allow for the comparison of brain activation between anxiety disorders, to see if differences exist. Furthermore, an additional limitation addressed in chapter 4, part 2 was the lack of depression data collected. As depression and anxiety commonly co-occur (Kaitz et al., 2010) it was deemed appropriate to include measures of depression in future studies to gain a better understanding of the interaction of these two disorders. Although depression levels can be measured using the

HADS, if a more rigorous measure of anxiety is to be adopted then it is advisable to remain consistent will all measures. The PDSQ also includes a scale for the measurement of Major Depressive Disorder (MDD) which is deemed as reliable and valid within the field (Zimmerman & Mattia, 2001).

Another potential limitation of the overall thesis was the statistical analyses which were employed. Within each chapter (with the exception of chapter 4 part 2), several multiple comparisons were conducted, including ANOVAs and t-tests were then to explore between group differences. Due to the amount comparisons conducted on the data, this could have made the analyses subject to a type one error, which is the incorrect rejection of the null hypothesis, meaning that significant results may have been found where they did not exist (Field, 2013; Pallant, 2013). Typically a Bonferroni correction is used where multiple comparisons are performed to control for type one errors (Field, 2013; Pallant, 2013). The Bonferroni raises the critical value of the statistical test according to how many tests are being carried out which reduces the likelihood of a type one error occurring (Field, 2013; Pallant, 2013). Despite Bonferroni corrections not being conducted within the current thesis, significant results found within each chapter were highly significant and also had medium or large effect sizes. This therefore suggests that the effects found were unlikely to have occurred by chance.

A final limitation of the overall thesis was not collecting behavioural data from the infants or mothers. Links were made in this thesis between EEG data and existing behavioural studies to interpret patterns of brain functioning, for example, how a negative EEG profile towards the non-social stimuli in female infants could actually reflect a behavioural preference for social stimuli. To address this issue, future work would be to include a measure which would assess infant behavioural preferences towards social and non-social stimuli. This would allow clearer and more direct links to be made between infant behaviour and brain functioning within the same sample. Additionally, if behavioural measures of maternal approach and avoidance traits were measured through the completion of the BIS and BAS (Carver & White, 1994), as discussed earlier in this section, more informative conclusions about the sample could also be drawn.

Further limitations relating to each study were also apparent, however these limitations and implications for future research have been discussed within their respective chapters.

6.6. Conclusion

In summary, this thesis set out to explore three main aims. Firstly to explore the experience of auditory social and non-social stimuli upon infants brain functioning. This thesis provided evidence that infants as young as 3-months old have specialised neural networks for processing language (social stimuli) which are not yet as fully developed as adults. A second aim was to explore the role of the prefrontal cortex (PFC) in social and non-social visual processing and anxiety. Social stimuli were found to impact infant frontal asymmetry patterns and furthermore, the gender of the impact also influenced brain activation in the PFC in response to social and non-social stimuli. Frontal asymmetries however were not found to be affected by infants who had mothers with low-trait anxiety. The final aim of the thesis was to investigate the effect of a mother's depression upon infant behaviour and results revealed that infants of depressed mothers do display higher levels of positive affect in comparison to infants of non-depressed mothers when engaged in a stressful situation with their mother.

In summary, this thesis has expanded our knowledge in the areas of social and non-social processing and emotion based disorders. Future work, is needed in these areas to further our understanding of the results obtained and to gain a clearer picture of the effects of emotion based disorders and social experiences upon infant brain functioning and behaviour.

APPENDIX

Demographic Questionnaire

I.D. ______________

Thank you for agreeing to be part of this study. Please tell us a little bit about yourself, so we know more about the families who are participating. Your answers are confidential, so please be completely honest in responding. If you have more than one child, please fill in this questionnaire about the child you have brought with you to take part in the study today.

1. What is your month and year of birth? ______________________

2. Which race/ethnic group best describes you? (please tick)

White/Caucasian ☐ Black/Black British ☐ Asian/Asian British ☐

Chinese ☐ Mixed ☐

Other☐________________________ (please specify)

3. Which of the following best describes your educational background? (tick only your highest qualification)

☐ Some secondary school education

☐ GCSEs

☐ A-levels

☐ Post-graduate certificates (e.g. PGCE)

☐ Master's degree

☐ Professional or Doctorate degree (e.g. Ph.D.)

☐ University graduate (e.g. Bachelor's degree)

Other: __________________________

5. Is there any history of mental health problems in your family?

____

4. Your child's day, month and year of birth? (please answer about the child participating in this study) _______________________

5. Your child's due date of birth? (please answer about the child participating in this study)

____

6. Please indicate the gender of your child (who is in this study):

male ☐ female ☐

7. Did you experience any birth complications when you gave birth to the child participating in this

study?

____

8. Has your child experienced any medical problems?

____

HAD Scale

[redacted]

Emotions play an important part in most illnesses. This questionnaire is designed to show us how you are feeling.

Read each item and place a tick in the box next to the reply that comes closest to **how you have been feeling in the past week.**

Don't take too long over your replies; your immediate reaction to each item will probably be more accurate than a long though-out response.

Tick only one box in each section

I feel tense or 'wound up':

☐ Most of the time
☐ A lot of the time
☐ Time to time, occasionally
☐ Not at all

I still enjoy the things I used to enjoy:

☐ Definitely as much
☐ Not quite so much
☐ Only a little
☐ Hardly at all

I get a sort of frightened feeling as if something awful is about to happen:

☐ Very definitely and quite badly
☐ Yes, but not too badly
☐ A little, but it doesn't worry me
☐ Not at all

I can laugh and see the funny side of things:

☐ As much as I always could

☐ Not quite so much now

☐ Definitely not so much now

☐ Not at all

Worrying thoughts go through my mind:

☐ A great deal of the time

☐ A lot of the time

☐ From time to time but not too often

☐ Only occasionally

I feel cheerful:

☐ Not at all

☐ Not often

☐ Sometimes

☐ Most of the time

I can sit at ease and feel relaxed:

☐ Definitely

☐ Usually

☐ Not often

☐ Not at all

I feel as if I am slowed down:

☐ Nearly all the time

☐

☐

☐

Very often

Sometimes

Not at all

I get a sort of frightened feeling like 'butterflies' in the stomach:

☐ Not at all
☐ Occasionally
☐ Quite often
☐ Very often

I have lost interest in my appearance:

☐ Definitely
☐ I don't take so much care as I should
☐ I may not take quite as much care
☐ I take just as much care as ever

I feel restless as if I have to be on the move:

☐ Very much indeed
☐ Quite a lot
☐ Not very much
☐ Not at all

I look forward with enjoyment to things:

☐ As much as I ever did
☐
☐
☐

Rather less than I used to

Definitely less than I used to

Hardly at all

I get sudden feelings of panic:

- ☐ Very often indeed
- ☐ Quite often
- ☐ Not very often
- ☐ Not at all

I can enjoy a good book or radio or TV programme:

- ☐ Often
- ☐ Sometimes
- ☐ Not often
- ☐ Very seldom

REFERENCES

Adolphs, R. (2001). The Neurobiology of Social Cognition. *Current Opinion in Neurobiology, 11,* 231-239. doi: 10.1016/S0959-4388(00)00202-6

Ahmad, Z., Balsamo, L. M., Sachs, B. C., Xu, B., & Gaillard, W. E. (2003). Auditory comprehension of language in young children- Neural networks identified with fMRI. *Neurology, 60,* 1598-1605. Doi: 10.1212/01.WNL.0000059865.32155.86

Ainsworth, M. D. S., & Bowlby, J. (1991). An ethological approach to personality development. *American Psychologist, 46*, 333–341. doi:10.1037//0003-066X.46.4.333

Allen, J. J. B., Urry, H. L., Hitt, S. K. &, Coan, J. A. (2004). The stability of resting frontal electroencephalographic asymmetry in depression. *Psychophysiology, 41*, 269–280. doi: 10.1111/j.1469-8986.2003.00149.x

Alku P, Tiitinen H, Naatanen R. (1999). A method for generating natural-sounding speech stimuli for cognitive brain research. *Clinical Neurophysiology, 110*, 1329–33. doi: 10.1016/S1388-2457(99)00088-7

American Psychiatric Association. (2013). Cautionary statement for forensic use of DSM-5. In *Diagnostic and statistical manual of mental disorders* (5th ed.). doi: 10.1176/appi.books.9780890425596.744053

Anderson, S. W., Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (1999). Impairment of social and moral behaviour related to early damage in human prefrontal cortex. *Nature Neuroscience, 2*, 1032 -1037.

Annett, M. (1972). The distribution of manual asymmetry. *British Journal of Psychology, 63*, 343–358. doi: 10.1111/j.2044-8295.1972.tb01282.x

Ashman, S. B., Dawson, G., Panagiotides, H., Yamada, E., & Wilkinson, C. W. (2002). Stress hormone levels of children of depressed mothers. *Development and Psychopathology, 14*, 333-349. doi: 10.1017/S0954579402002080

Audactity. Released 2010. Audacity, Version 1.3.12 America, Audacity.

Bachevalier, J., & Loveland, K.A. (2006). The orbitofrontal-amygdala circuit and self-regulation of social-emotional behavior in autism. *Neuroscience and Biobehavioral Reviews, 30* (1), 97-117. doi: 10.1016/j.neubiorev.2005.07.002

Baillet, S., J. Mosher, & R. Leahy (2001). Electromagnetic brain mapping. *IEEE Signal Processing Magazine, 18* (6), 14–30. doi: 10.1109/79.962275

Baker, S. C., Rogers, R. D., Owen, A. M., Frith, C. D., Dolan, R. J., Frackowiak, R. S. J., & Robbins, T. W. (1996). Neural systems engaged by planning: A PET study of the Tower of London task. *Neuropsychologia, 34,* 515. doi: 10.1016/0028-3932(95)00133-6

Balsamo, L. M., Xu, B., & Gaillard, W. D. (2006). Language lateralization and the role of the fusiform gyrus in semantic processing in young children. *Neuroimaging, 31*, 1306-1314. doi: 10.1016/j.neuroimage.2006.01.027

Barbas, H. (1995). Pattern in the cortical distribution of prefrontally directed neurons with divergent axons in the rhesus monkey. *Cerebral Cortex, 5,* 158-165. doi: 10.1093/cercor/5.2.158

Barlow, J. (2002). Antenatal anxiety , parenting and behavioural/emotional problems in children. *British Journal of Psychiatry, 181,*440-441. doi: 10.1192/bjp.181.5.440-a

Barnet, A. B. (1975). Auditory evoked potentials during sleep in normal children from ten days to 3 years of age. *Electroencephalography clinical Neurophysiology, 39* (1), 29–41.

Baron-Cohen, S., Ring, H. A., Wheelwright, S., Bullmore, E. T., Brammer, M. J., Simmons, A., et al. (1999). Social intelligence in the normal and autistic brain: an fMRI study. *Journal of Neuroscience, 11*(6), 1891-8. doi: 10.1046/j.1460-9568.1999.00621.x

Beaton, E. A., Schmidt, L.A., Ashbaugh, A. R., Santesso, D. L., Antony, M. M., & McCabe, R. E. (2008). Resting and reactive frontal brain electrical activity (EEG) among a non-clinical sample of socially anxious adults: Does concurrent depressive mood matter? *Neuropsychiatric Disease and Treatment, 4(*1*),* 187-192.

Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition 50*, 7-15. doi: 10.1016/0010-0277(94)90018-3

Bechara, A., Dolan, S., Denburg, N., Hindes, A., Anderson, S. W., & Nathan, P.E. (2001). Decision-making deficits linked to a dysfunctional ventromedial prefrontal cortex, revealed in alcohol and stimulant abusers. *Neuropsychologia, 39,* 376-389. doi: 10.1016/S0028-3932(00)00136-6

Bedford, R., Pickles, A., Gliga, T**.,** Elsabbagh, M., Charman, T., Johnson, M. H. & The BASIS Team (2014). Additive effects of social and non-social attention during infancy relate to later Autism Spectrum Disorder. *Developmental Science,* 1-9. doi: 10.1111/desc.12139

Belger, A., Puce, A., Krystal, J. H., Gore, J. C., Goldman-Rakic, P., & McCarthy, G. (1998). Dissociation of mnemonic and perceptual processes during spatial and nonspatial working memory using fMRI. *Human Brain Mapping, 6*, 14–32. doi: 10.1002/(SICI)1097-0193(1998)6:1<14::AID-HBM2>3.3.CO;2-2

Bell, M. A., & Wolfe, C. D. (2007). Changes in brain functioning from infancy to early childhood: Evidence from EEG power and coherence during working memory tasks. *Developmental Neuropsychology, 31***,** 21-38. doi: 10.1207/s15326942dn3101_2

Bernard-Bonnin, A. C. (2004). Position statement: Maternal depression and child development. *Paediatrics & Child Health, 9*, 575-583.

Bjelland, I., Dahl, A. A., Haug, T. T., & Neckelmann, D. (2002). The validity of the Hospital Anxiety and Depression Scale - An updated literature review. *Journal of Psychosomatic Research ,52* (2), 69-77.

Blissett, J., Meyer, C., & Haycraft, E. (2007). Maternal mental health and child feeding problems in a non-clinical group. *Eating Behaviors, 8*, 311-318. doi: 10.1016/j.eatbeh.2006.11.007

Bosch, L., & Sebastián-Gallés, N. (1997). Native-language recognition abilities in 4-month-old infants from monolingual and bilingual environments. *Cognition, 65*(1), 33–69. doi: 10.1016/S0010-0277(97)00040-1

Braungart-Rieker, J. M., Garwood, M. M., Powers, B. P., & Wang, X. Y. (2001). Parental sensitivity, infant affect, and affect regulation: Predictors of later attachment. *Child Development, 72*, 252–270. doi:10.1111/1467-8624.00277

Brennan, P. A., Pargas, R., Walker, E. F., Green, P., Newport, J. D., & Stowe, Z. (2008). Maternal depression and infant cortisol: influences of timing, comorbidity and treatment. *Journal of Child Psychology and Psychiatry, 49* (10), 1099-1107. doi: 10.1111/j.1469-7610.2008.01914.x

Bretherton, I. (1992). The origins of attachment theory: John Bowlby and Mary Ainsworth. *Developmental Psychology, 28*, 759-775. doi: 10.1037//0012-1649.28.5.759

Brothers, L. (1995). Neurophysiology of the perception of intentions by primates. In M. S. Gazzaniga (EDs.), *The cognitive neurosciences* (pp 1107-1115). Cambridge, MA, US: The MIT Press.

Brown, S. E., Varghese, F. P., & McEwen, B. S. (2004). Association of depression with medical illness: does cortisol play a role? *Biological Pscyhiatry, 55* (1), 1-9.

Bryson, S. E., Zwaigenbaum, L., Brian, K., Roberts, W., Szatmari, P., Rombough, V. et al. (2007). A prospective case series of high-risk infants who developed autism. *Journal of Autism and Developmental disorders, 37* (1), 12-24. doi: 10.1007/s10803-006-0328-2

Butterworth, G., & Hopkins, B. (1993). Origins of handedness in human infants. *Developmental Medicine and Child Neurology, 35*, 177–184. doi: 10.1111/j.1469-8749.1993.tb11620.x

Calkins, S. D., Fox, N. A., & Marshall, T. R. (1996). Behavioral and physiological antecedents of inhibited and uninhibited behavior. *Child Development, 67*, 523-554. doi: 10.2307/1131830

Carver, C.S. & White, T.L. (1994). Behavioural inhibition, behavioural activation, and affective responses to impending reward and punishment: the BIS/BAS scales. *Journal of personality and social psychology, 67*, 319 – 333. doi: 10.1037//0022-3514.67.2.319

Ceponiene, R., Rinne, T., Naatanen, R. (2002). Maturation of cortical sound processing as indexed by event-related potentials. *Clinical Neurophysiology, 113* (6), 870–82.

Ceponiene, R., Torki, M., Alku, P., Koyama, A., & Townsend, J. (2008). Event-related potentials reflect spectral differences in speech and non-speech stimuli in children and adults. *Clinical Neurophysiology, 119*, 1560–1577.

Chaudieu, I., Beluche, I., Norton, J., Boulenger, J. P., Ritchie, K., & Ancelin, M. L. (2008). Abnormal reactions to environmental stress in elderly persons with anxiety disorders: evidence from a population study of diurnal cortisol changes.*Journal of Affective Disorders, 106* (3), 307-13. doi: 10.1016/j.jad.2007.07.025

Chou, T. L., Booth, J. R., Burman, D. D., Bitan, T., Bigio, J. D., Lu, D. et al. (2006). Developmental changes in the neural correlates on semantic processing. *Neuroimaging, 29,* 1141-1149. doi: 10.1016/j.neuroimage.2005.09.064

Coan, J. A., & Allen, J. J. B. (2003). The state and trait nature of frontal EEG asymmetry in emotion. In: Hugdahl K., Davidson. R. J., editors. The Asymmetrical Brain. Cambridge, MA: MIT Press. pp 565-615.

Coan, J. A., Schaefer, H. S., & Davidson, R. J. (2006). Lending a hand: Social regulation of the neural response to threat. *Psychological Science, 17*, 1032–1039. doi: 10.1111/j.1467-9280.2006.01832.x

Cohn, J. E., Campbell, S. B., Matias, R., & Hopkins, J. (1990). Face-to-face interactions of postpartum depressed and non-depressed mother–infant pairs at two months. *Developmental Psychology*, *26*, 12–23.

Colombo, J., & Bundy, R. S. (1981). A method for the measurement of infant auditory selectivity. *Infant Behavior and Development, 4*, 219–223.

Connellan, J., Baron-Cohen, S.,Wheelwright, S., Batki,A. & Ahluwalia, J. (2000). Sex differences in human neonatal social perception. *Infant Behavior and Development, 23*, 113–118. doi: 10.1016/S0163-6383(00)00032-1

Cooper, R. P., & Aslin, R. N. **(**1990**).** Preference for infant- directed speech in the first month after birth. *Child Development, 61*, 1584-1595. doi: 10.2307/1130766

Corballis, M. C., Badzakova-Trajkov, G., & Häberling, I. S. (2012). Right hand,left brain: genetic and evolutionary bases of cerebral asymmetries for language and manual action. *Cognitive Science, 3*, 1–17. doi: 10.1002/wcs.158

Courtney, S. M., Ungerleider, L. G., Keil, K., & Haxby, J. V. (1997). Transient and sustained activity in a distributed neural system for human working memory. *Nature, 386*, 608-611. doi: 10.1038/386608a0

Cowan, N. (1995). *Attention and memory: An integrated framework.* New York: Oxford University Press.

Coyne, J. C., & van Sonderen, E. (2012). No further research needed: abandoning the Hospital and Anxiety Depression Scale (HADS). *Journal of psychosomatic research, 72 (3), 174-174.* doi: 10.1016/j.jpsychores.2011.12.003

Curtis,C.E., & D'Esposito, M. (2003). Persistent activity in the prefrontal cortex during working memory. *Trends In Cognitive Science, 7*, 415–423. doi:10.1016/S1364-6613(03)00197-9. doi: 10.1016/S1364-6613(03)00197-9

Cutting, J. E., & Kozlowski, L. T. (1976). .Recognizing friends by their walk: Gait perception without familiarity cues *Bulletin of the Psychonomic Society, 9*, 353- 356.

Davidson, R.J. (2004). What does the prefrontal cortex "do" in affect: perspectives on frontal EEG asymmetry research. *Biological Psychology, 67,* 219-233. doi: 10.1016/j.biopsycho.2004.03.008

Davidson, R. J., & Fox, N. A. (1989). Frontal Brain Asymmetry Predicts Infants' Response to Maternal Separation. *Journal of Abnormal Psychology, 98* (2), 127-131. doi: 10.1037/0021-843X.98.2.127

Davidson, R.J. & Irwin, W. (1999). The functional neuroanatomy of emotion and affective style. *Trends in Cognitive Science, 3*, 11–21. doi: 10.1016/S1364-6613(98)01265-0

Davidson, R. J., Ekman, P., Saron, C. D., Senulis, J. A., & Friesen, W. V. (1990). Approach-Withdrawal and Cerebral Asymmetry: Emotional Expression and Brain Physiology: I. *Journal of Personality and Social Psychology, 58*(2)*,* 330-341. doi: 10.1037//0022-3514.58.2.330

Dawson, G. (1994). Frontal Electroencephalographic Correlates of Individual Differences in Emotion Expression in Infants: A Brain Systems Perspective on Emotion. *Monographs of the Society for Research in Child Development, 59*(3)*,* 135-151. doi: 10.2307/1166142

Dawson, G., Frey, K., Panagiotides, H., Osterling, J., & Hessi, D. (1997). Infants of depressed mothers exhibit atypical frontal brain activity: A replication and extensionof previous findings. *Journal of Child Psychology and Psychiatry*, *38*, 179–186. 10.1111/j.1469-7610.1997.tb01852.x

Dawson, G., Panagiotides, H., Klinger, L. G., & Hill, D. (1992). The Role of Frontal Lobe Functioning in the Development of Infant Self-Regulatory Behaviour. *Brain and Cognition, 20,* 152-175. doi: 10.1016/0278-2626(92)90066-U

DeBoer, T., Scott, L. S., & Nelson, C. A. (2007). Methods for acquiring and analysing infant event-related potentials. In de Haan, M. (Ed.), *Infant EEG and Event-Related Potentials: Studies in Developmental Psychology* (pp. 5-37). East Sussex: Psychology Press.

DeCasper, A. J., & Fifer, W. P. (1980). Of human bonding: Newborns prefer their mothers' voices. *Science, 208*, 1174–1176. doi: 10.1126/science.7375928

Dehaene-Lambertz, G. (2000). Cerebral specialization for speech and non-speech stimuli in infants. *Journal of Cognitive Neuroscience*, 12 (3), 449-460.

Dehaene-Lambertz, G., & Baillet, S. (1998). A phonological representation in the infant brain. *NeuroReport, 9(*8), 1885-1888. doi: 10.1097/00001756-199806010-00040

Dehaene-Lambertz, G., & Dehaene, S. (1994). Speed and cerebral correlates of syllable discrimination in infants. *Nature, 370*, 292-295. doi: 10.1038/370292a0

Dehaene-Lambertz, G., Dehaene, S., & Hertz-Pannier, L. (2002). Functional Neuroimaging of Speech Perception in Infants. *Science, 298,* 2013-2015. doi: 10.1126/science.1077066

Dehaene-Lambertz, G., Hertz-Pannier, L., Dubois, J., Me'Riaux S., Roche, A., Sigman, M., et al. (2006). Functional organization of perisylvian activation during presentation of sentences in preverbal infants. *PNAS, 103*(38), 14240-14245. doi: 10.1073/pnas.0606302103

Diego, M. A., Field, T., Hart, S., Hernandez-Reif, M., Jones, N., Cullen, C., et al. (2002). Facial expressions and EEG in infants of intrusive and withdrawn mothers with depressive symptoms. *Depression and Anxiety, 15,* 10-17. doi: 10.1002/da.1079

Diego, M. A., Field, T., Hernandez-Reif, M., Cullen, C., Schanberg, S., & Kuhn, C. (2004). Prepartum, postpartum, and chronic depression effects on newborns. *Psychiatry, 67*, 63-80.

Diego, M. A., Field, T., Jones. N. A., & Hernandez-Reif, M. (2006). Withdrawn and intrusive maternal interaction style and infant frontal EEG asymmetry shifts in infants of depressed and non-depressed mothers. *Infant Behaviour and Development, 29*(2), 220 -229. doi: 10.1016/j.infbeh.2005.12.002

Di Giorgio, E., Turati, C., Altoe, G., & Simion, F. (2012). Face detection in complex visual displays: An eye-tracking study with 3-and 6-month-old infants and adults. *Journal of experimental child psychology, 113* , 66-77. doi: 10.1016/j.jecp.2012.04.012

Dronkers, N. F., Wilkins, D. P., Van Valin, R. D., Redfern, B. B., & Jaeger, J. J. (2004). Lesion analysis of the brain areas involved in language comprehension. *Cognition, 92(1-2)*, 145 – 177. doi: 10.1016/j.cognition.2003.11.002

Elk, M., Schie, H. T., Zwaan, R. A., & Bekkering, H. (2010). The functional role of motor activation in language processing: Motor cortical oscillations support lexical-semantic retrieval. *Neuroimage, 50,* 665-677.

Elsabbagh, M., Fernandes, J., Webb, S. J., Dawson, G., Charman, T., Johnson, M. H. et al. (2013). Disengagement of visual attention in infancy is associated with emerging autism in toddlerhood. *Biological Psychiatry, 74* (3), 198-194.

Essex, M. J., Klein, M. H., Cho, E., & Kalin, N. H. (2002). Maternal stress beginning in infancy may sensitize children to later stress exposure: Effects on cortisol and behavior. *Biological Psychiatry, 52*, 776-784. doi: 10.1016/S0006-3223(02)01553-6

Feldman, R., Greenbaum, C. W., Mayes, L. C., & Erhlich, S. H. (1997). Change in mother–infant interactive behavior: Relations to change in the mother,the infant, and the social context. Infant Behavior and Development, 20, 151–163. doi: 10.1016/S0163-6383(97)90018-7

Fellows, L. K, & Farah, M. J. (2005). Different underlying impairments in decision-making following ventromedial and dorsolateral frontal lobe damage in humans. *Cerebral Cortex, 15,* 58-63. doi: 10.1093/cercor/bhh108

Field, T. (1994). The effects of mother's physical and emotional unavailability on emotion regulation. *Monographs of the Society for Research in Child Development, 59*, 208–227. doi: 10.2307/1166147

Field, T. (2002). Early interactions between infants and their postpartum depressed mothers. *Infant Behavior & Development, 25 (1)*, 25-29. doi: 10.1016/S0163-6383(02)00089-9

Field, T. (2010). Postpartum depression effects on early interactions, parenting, and safety practices: A review. *Infant Behaviour and Development, 33(1),* 1-6. doi: 10.1016/j.infbeh.2009.10.005

Field, A. (2013). *Discovering Statistics using IBM SPSS Statistics*. London: Sage Publications Ltd.

Field, T., & Diego, M. (2008). Maternal Depression effects on Infant Frontal EEG Asymmetry. *International Journal of Neuroscience,* 118, 1081-1108. doi: 10.1080/00207450701769067

Field, T., Diego, M., & Hernandez-Reif, M. (2009). Depressed mothers' infants are less responsive to faces and voices. *Infant Behaviour and Development,32,* 239-244

Field, T., Diego, M., Hernandez-Reif, M., Schanberg, S., & Kuhn, C. (2003). Depressed mothers who are "good interaction" partners versus those who are withdrawn or intrusive. *Infant Behaviour and Development, 26,* 238-252. doi: 10.1016/S0163-6383(03)00020-1

Field, T., Healy, B, Goldstein, S., & Guthertz, M. (1990). Behaviour-State Matching and Synchrony in Mother-Infant Interactions of Nondepressed Versus Depressed Dyads. *Developmental Psychology, 26(1),* 7-14. doi: 10.1037/0012-1649.26.1.7

Field, T., Hernandez-Reif, M., Diego, M., Feijo, L., Vera, Y., Gil, K., et al. (2007). Still-face and separation effects on depressed mother–infant interactions. *Infant Mental Health Journal, 28*, 314–323. doi: 10.1002/imhj.20138

Field, T., Vega-Lahr, N., Scafidi, F., & Goldstein, S. (1986). Effects of maternal unavailability on mother–infant interactions. *Infant Behavior & Development, 9*, 473–478. doi: 10.1016/0163-6383(86)90019-6

Fingelkurts, A. A., Fingelkurts, A. A., Rytsala, H., Suominen, K, Isometsa, E., & Kahkonen, S. (2007). Impaired Functional Connectivity at EEG Alpha and Theta Frequency Bands in Major Depression. *Human Brain Mapping, 28,* 247-261. doi: 10.1002/hbm.20275

Forbes, E. E., Cohn, J. F., Allen, N. B., & Lewinsohn, P. M. (2004). Infant affect during parent- infant interaction at 3 and 6 months: Differences between mothers and fathers and influence of parent history of depression. *Infancy, 5*, 61–84. doi: 10.1207/s15327078in0501_3

Fox, N. A., & Davidson, R. J. (1987). Electroencephalogram asymmetry in response to the approach of a stranger and maternal separation in 10 month old infants. *Developmental Psychology, 23,* 233-240. doi: 10.1037//0012-1649.23.2.233

Fox, N. A. & Henderson, H. A. (1999). Does infancy matter? Predicting social behaviour from infant temperament. *Infant Behaviour & Development, 22* (4), 445-455. doi: 10.1016/S0163-6383(00)00018-7

Fox, N. A., Henderson, H. A., Rubin, K. H., Calkins, S. D., & Schmidt, L. A. (2001). Continuity and Discontinuity of Behavioural Inhibition and Exuberance: Psychophysiological and Behavioural Influences across the First Four Years of Life. *Child Development, 72* (1)*,* 1-21. doi: 10.1111/1467-8624.00262

Gartstein, M. A., & Rothbart, M. K. (2003). Studying infant temperament via the Revised Infant Behavior Questionnaire. *Infant Behavior & Development, 26,* 64–86. doi: 10.1016/S0163-6383(02)00169-8

Friederici, A. D. (2006). The Neural Basis of Language Development and Its Impairment. *Neuron, 52* (6), 941-952. doi: 10.1016/j.neuron.2006.12.002

Friedrich, M., & Friederici, A. D. (2004). N400-like semantic incongruity effect in 19month-olds: Processing known words in picture contexts. *Journal of Cognitive Neuroscience, 16*, 1465–1477. doi: 10.1162/0898929042304705

Friedrich, M., & Friederici, A. D. (2005). Lexical priming and semantic integration reflected in the event-related potential of 14-month-olds. *NeuroReport, 16*, 653–656. doi: 10.1097/00001756-200504250-00028

Friedrich, M., & Friederici, A. D. (2010). Maturing brain mechanisms and developing behavioral language skills. *Brain and Language, 114*, 66–71. doi: 10.1016/j.bandl.2009.07.004

Gable, P.A., & Harmon-Jones, E. (2008). Approach-motivated positive affect reduces breadth of attention. *Psychological Science, 19*, 476–482. doi: 10.1111/j.1467 9280.2008.02112.x

Garrido, M. I., Kilnar, J. M., Stephan, K. E., & Fritson, K. J. (2009). The mismatch negativity: A review of underlying mechanisms. *Clinical Neurophysiology, 120* (3), 453-463. doi: 10.1016/j.clinph.2008.11.029

Gelebenberg,A. J. (2010). Optimizing depression treatment to increase the likelihood of remission. *Journal of Clinical Psychiatry, 71* (9), e22. doi: 10.4088/JCP.9078tx2c. doi: 10.4088/JCP.9078tx2c

Gliga, T., & Csibra, G. (2007). Seeing the face through the eyes: a developmental perspective on face expertise. *Progress in Brain Research,* 323-339.

Gliga**,** T**.,** & Dehaene**-**Lambertz**,** G. **(**2005**).** Structural encoding of body and face in human infants and adults. *Journal of Cognitive Neuroscience, 17*, 1328–1340. doi: 10.1162/0898929055002481

Gliga, T., Elsabbagh, M., Andravizou, A., & Johnson, M. (2009). Faces attract infants' attention in complex displays. *Infancy, 14* , 550-562. doi: 10.1080/15250000903144199

Golkar, A., Lonsdorf, T. B., Olsson, A., Lindstrom, K. M., Berrebi, J., et al. (2012). Distinct Contributions of the Dorsolateral Prefrontal and Orbitofrontal Cortex during Emotion Regulation. *PLOS ONE, 7*(11), e48107. doi: 10.1371/journal.pone.0048107

Grave de Peralta Menendez, R. & S. Gonzalez Andino (1998). A critical analysis of linear inverse solutions to the neuroelectromagnetic inverse problem. *IEEE Transactions on Biomedical Engineering, 45*, 440–448. doi: 10.1109/10.664200

Greene, D. J., & Zaidel, E. (2011). Hemispheric differences in attentional orienting by social cues. *Neuropsychology, 49*(1), 61-68. doi: 10.1016/j.neuropsychologia.2010.11.007

Grieve, P. G., Isler, J. R., Izraelita, A., Peterson, B. S., Fifer, W. P., Myers, M. M. et al. (2008). EEG functional Connectivity in Term Age Extremely Low Birth Weight Infants. *Clinical Neuropsychology, 119 (12), 2712-2720.* doi:10.1016/j.clinph.2008.09.020

Grossmann, T., & Johnson, M. H. (2007). The development of the social brain in infancy. *European Journal of Neuroscience, 25*, 909–919. doi: 10.1111/j.14609568.2007.05379.x.

Grossmann, T., Striano, T., & Friederici, A. D. (2006). Crossmodal integration of emotional information from face and voice in the infant brain. *Developmental Science, 9*(3), 309-315. doi: 10.1111/j.1467-7687.2006.00494.x

Gunnar, M., & Donzella, B., (2001). Social regulation of the HPA axis in early human development. *Psychoneuroendocrinology, 27*, 199–220.

Gusella, J. L., Muir, D., & Tronick, E. Z. (1988). The effect of manipulating maternal behavior during an interaction on three- and six-month-olds' affect and attention. *Child Development, 59*, 1111–1124. doi: 10.2307/1130278

Gutteling, B. M., de Weerth, C., Buitelaar, J. K. (2005). Prenatal stress and children's cortisol reaction to the first day of school. *Psychoneuroendocrinology, 30*, 541-549. doi: 10.1016/j.psyneuen.2005.01.002

Haan, M., Belsky, J., Reid, V., Volein, A. & Johnson, M. H. (2004). Maternal personality and infants' neural and visual responsivity to facial expressions of emotion. *Journal of Child Psychology and Psychiatry, 45* (7), 1209-1218. doi: 10.1111/j.1469-7610.2004.00320.x

Halle, P. A., & De Boysson-Bardies, B. (1996). The format of representation of recognized words in infants' early receptive lexicon. *Infant Behavior and Development, 19,* 463–481. doi: 10.1016/S0163-6383(96)90007-7

Hane, A. A., Fox, N. A., Henderson, H., & Marshall, P. J. (2008). Early behavioral reactivity and approach-withdrawal bias in infancy. *Developmental Psychology, 44,* 1491–1496.

Harris, M., Yeeles, C., Chasin, J., & Oakley, Y. (1995). Symmetries and asymmetries in early lexical comprehension and production. *Journal of Child language, 22*, 1-18. doi: 10.1017/S0305000900009600

Henderson, H. A., Fox, N. A., & Rubin, K. H. (2001).Temperamental contributions to social behavior: The moderating roles of frontal EEG asymmetry and gender. *Journal of the American Academy of Child and Adolescent Psychiatry, 40,* 68–74. doi: 10.1097/00004583-200101000-00018

Henriques, J. B., & Davidson, R. J. (1991). Left Frontal Hypoactivation in Depression. *Journal of Abnormal Psychology, 100*(4)*,* 535-545. doi: 10.1037//0021-843X.100.4.535

Heron, M., & Slaughter, V. (2010). Infants' responses to real humans and representations of humans. *International Journal of Behavior and Development, 34*, 34-45. doi: 10.1177/0165025409345047

Herrmann, C. (1997). International experiences with the Hospital Anxiety and Depression Scale: a review of validation data and clinical results. *Journal of Psychosomatic Research, 42,* 17-41. doi: 10.1016/S0022-3999(96)00216-4

Hickok G., & Poeppel, D. (2007). The cortical organization of speech. *Nature Reviews Neuroscience, 8*, 393 – 402. doi: 10.1038/nrn2113

Hirai, M., & Hiraki, K. (2005). An event-related potential study of biological motion perception in human infants. *Cognitive Brain Research, 22 (2)*, 301-304. doi: 10.1016/j.cogbrainres.2004.08.008

Hornak, J., Bramham, J., Rolls, E. T., Morris, R. G, O'Doherty, J., Bullock, P. R., et al. (2003). Changes in emotion after circumscribed surgical lesions of the orbitofrontal and cingulate cortices. *Brain: a journal of neurology, 126*(7), 1691-1712. doi: 10.1093/brain/awg168

Hoskyn, M. (2010). Working Memory in Infancy and Early Childhood: What Develops? In B. Sokol, & U. Muller (ED.), *Self- and Social-Regulation: Exploring the Relations Between Social Interaction, Social Understanding, and the Development of Executive Functions*. (pp. 155-184). Online: Oxford University Press. doi: *10.1093/acprof:oso/9780195327694.003.0007*

Johansson, G. (1975). Visual motion perception. *Scientific American, 232,* 76–88. doi: 10.3758/BF03212378

Johnson, M. H., Dziuraweic, S., Ellis, H., & Morton, J. (1991). Newborns' preferential tracking of face-like stimuli and its subsequent decline. *Cognition, 40*, 1-19. doi: 10.1016/0010-0277(91)90045-6

Johnson, M.H. & Farroni, T. (2007). The neurodevelopmental origins of eye-gaze perception. In: R. Flom, K. Lee and D. Muir (Ed.), *Gaze-Following: Its Development and Significance* (pp. 1-16). Mahwah, NJ: Laurence Erlbaum Associates.

Johnson, M. H., & Morton, J. (1991). Biology and Cognitive Development: The Case for Face Recognition. Oxford, UK: Blackwell.

Jones, N. A., Field, T., & Almeida, A. (2009). Right frontal EEG asymmetry and behavioural inhibition in infants of depressed mothers. *Infant Behaviour and Development, 32,* 298-304. doi: 10.1016/j.infbeh.2009.04.004

Jones, N., Field, T., Davalos, M., & Pickens, J. (1997). EEG stability in infants/children of depressed mothers. *Child Psychiatry and Human Development*, *28*, 59–70.

Jones, N. A., Field, T., Fox, N. A., Lundy, B., & Davalos, M. (1997). EEG activation in one-month old infants of depressed mothers. *Development and Psychopathology, 9*, 491-505.

Jones, N. A., Field, T., Hart, S., Lundy, B., & Davalos, M. (2001). Maternal self-perceptions and reactions to infant crying among intrusive and withdrawn depressed mothers. *Infant Mental Health Journal, 22*, 576–586. doi: 10.1002/imhj.1019

Kaan, E. (2007). Event-Related Potentials and Language Processing: A Brief Overview. *Language and Linguistics Compass, 1* (6), 571-591. doi: *10.1111/j.1749 818x.2007.00037.x*

Kaitz, M., & Maytal, H. (2005). Interactions Between Anxious Mothers and Their Infants: An Integration of Theory and Research Findings. *Infant Mental Health Journal, 26(6),* 570-597. doi: 10.1002/imhj.20069

Kaitz, M., Maytal., R. H., Devor., Bergman, L., & Mankuta, D. (2010). Maternal anxiety, mother-infant interactions, and infants' response to challenge. *Infant Behaviour and Development, 33,* 136-148. doi: 10.1016/j.infbeh.2009.12.003

Kaldy, Z., & Sigala, N. (2004). The neural mechanisms of object working memory: What is where in the infant brain? *Neuroscience and Biobehavioral Reviews, 28*, 113-121.

Kawasaki, H., Kaufman, O., Damasio, H., Damasio, A. R., Granner, M., Bakken, H., et al. (2001). Single-neuron responses to emotional visual stimuli recorded in human ventral prefrontal cortex. *Nature Neuroscience, 4,* 15–16.

Keller, S. S., Crow, T., Foundas, A., Amunts, K., & Roberts, N. (2009). Broca's area: Nomenclature, anatomy, typology and asymmetry. *Brain and Language, 109* (1), 29 – 48.

Kessler, R. C., Chiu, W. T., Demler, O., Merikangas, K. R., & Walters, E. E. (2005). Prevalence, severity, and comorbidity of 12-month DSM-IV disorders in the National Comorbidity Survey Replication. *Archive of General Psychiatry, 62* (6), 617-627.

Kessler, R. C., Keller, M. B., & Wittchen, H. U. (2001). The epidemiology of generalized anxiety disorder. *The psychiatric clinics of North America, 24*(1), 19-39. doi: 10.1111/j.0065-1591.2000.acp29-02.x

Khosravizadeh, P., & Teimournezhad, S. (2011). *Handedness and Lateralization of the Brain. BRAIN, 2* (1), 2067-3957.

Kisilevsky, B. S., Hains, S. M. J., Lee, K., Xie, X., Huang, H., Ye, H. H., et al. (2003). Effects of experience on fetal voice recognition. *Psychological Science, 14,* 220–224. doi: 10.1111/1467-9280.02435

Klingberg, T. (2006). Development of a superior frontal-intraparietal network for visuo spatial working memory. *Neuropsychologia, 44* (11), 2171-2177. doi: 10.1016/j.neuropsychologia.2005.11.019

Kotilahti, K., Nissila, I., Nasi, T., Lipiainen, L., Noponen, T., Merilainen, P., et al. (2010). Hemodynamic Responses to Speech and Music in Newborn Infants. *Human Brain Mapping, 31*, 595-603. doi: 10.1002/hbm.20890

Kozlowski, L. T. and Cutting, J. E. (1977). Recognizing the sex of a walker from a dynamic point-light display. *Perception & Psychophysics, 21*, 575–580. doi: 10.3758/BF03198740

Kushnerenko, E., Ceponiene, R., Fellman, V., Huotilainen, M., & Winkler, I. (2001). Event-related potential correlates of sound duration: Similar pattern from birth to adulthood. *Neuroreport, 12*, 3777-3781. doi: 10.1097/00001756-200112040-00035

Kutas, M., & Hillyard, S. A. (1980). Event-related brain potentials to semantically inappropriate and surprisingly large words. *Biological Psychology, 11*, 99-116. doi: 10.1016/0301-0511(80)90046-0

Laine, K., Heikkinen, T., Ekblad, U., & Kero, P. (2003). Effects of Exposure to Selective Serotonin Reuptake Inhibitors During Pregnancy on Serotonergic Symptoms in Newborns and Cord Blood Monoamine and Prolactin Concentrations. *JAMA Psychiatry, 60* (7), 720-726.

Lindsley, D. B., & Wicke, J. D. (1974). The electroencephalogram: Antonomous electrical activity in man and animals. In R. Thompson & M. N. Patterson (Eds.), Bioelectric recording techniques (pp. 3-79) New York: Academic Press

Lloyd-Fox, S., Blasi, A., Everdell, N., Elwell, C. E., & Johnson, M. H. (2011). Selective cortical mapping of biological motion processing in young infants. *Journal of Cognitive Neuroscience, 23*, 2521–2532. doi: 10.1162/jocn.2010.21598. doi: 10.1162/jocn.2010.21598

LoBue, V., Coan, J. A.,Thrasher, C., & DeLoache, J. S. (2011). Prefrontal Asymmetry and Parent-Rated Temperament in Infants. *PLOS ONE, 6*(7), e22694. doi: 10.1371/journal.pone.0022694

Lundy, B. L., Jones, N. A., Field, T., Nearing, G., Davalos, M., Pietro, P. A., et al. (1999). Prenatal depression effects on neonates. *Infant Behavior and Development, 22*, 119 129. doi: 10.1016/S0163-6383(99)80009-5

Lutchmaya, S., & Baron-Cohen, S. (2002). Human sex differecnes in social and non-social looking preferecnes at 12 months of age. *Infant Behavior and Development,25,* 319-325.

Lutchmaya, S., Baron-Cohen, S., & Raggatt, P. (2002). Foetal testosterone and eye contact in 12 month old infants. *Infant Behavior and Development,25,* 327-335. doi: 10.1016/S0163-6383(02)00094-2

Macchi Cassia, V., Turati, C., & Simion, F. (2004). Can a Nonspecific Bias Toward Top-Heavy Patterns Explain Newborns' Face Preference? *Psychological Science, 15* (6), 379-384.

Manian, N., & Bornstein, M. H. (2009). Dynamics of emotion in infants of clinically depressed and nondepressed mothers. *Journal of Child Psychology and Psychiatry, 50*, 1410-1418. doi: 10.1111/j.1469-7610.2009.02166.x

Mantella, R. C., Butters, M. A., Amico, J. A., Mazumdar, S., Rollman, B. L., Begley, A. E., et al. (2008). Salivary cortisol is associated with diagnosis and severity of late-life generalized anxiety disorder. *Psychoneuroendocrinology, 33* (6), 773-81. doi: 10.1016/j.psyneuen.2008.03.002

Mars, R. B., & Grol, M. J. (2007). Dorsolateral prefrontal cortex, working memory, and prospective coding for action. *Journal of Neuroscience, 27*, 1801-1802. doi: 10.1523/JNEUROSCI.5344-06.2007

Marschik, P. B., Einspieler, C., Strohmeier, A., Plienegger, J., Garzarolli, B., & Prechtl, H. (2008). From the reaching behaviour at 5 months of age to hand preference at preschool age. *Developmental Psychobiology, 50*, 511–518. doi: 10.1002/dev.20307

Martin, N. (2006). *Human Neuropsychology*. Essex: Pearson Education Limited.

Maurer, D., & Barrera, M. (1981). Infants' perception of natural and distorted arrangements of a schematic face. *Child Development, 52*, 196-202. doi: 10.2307/1129230

McDowel, I. (2006). *Measuring Health: A guide to rating scales and questionnaires*. Oxford: Oxford University Press. doi: 10.1093/acprof:oso/9780195165678.001.0001

McEwen, B. S. (1998). Protective and damaging effects of stress mediators. *New England Journal of Medicine, 338* (3), 171-179.

Meltzoff, A. N., & Moore, M. K. (1997). Explaining facial imitation: A theoretical model. *Early Development and Parenting, 6*, 179-192. doi: 10.1002/(SICI)1099-0917(199709/12)6:3/4<179::AID-EDP157>3.0.CO;2-R

Menyuk, P., & Menn, L. (1979). Early strategies for the perception and production of words and sounds. In P. Fletcher & M. Garman (eds), Language acquisition : studies in first language development. Cambridge: CUP. doi: 10.1017/CBO9780511620683.012

Mesman, J., Van IJzendoorn, M. H., & Bakermans-Kranenburg, M. J. (2009). The many faces of the still-face paradigm: A review and meta-analysis. *Developmental Review, 29*, 120-162. doi: 10.1016/j.dr.2009.02.001

Meyer, M. L. & Lieberman, M. D. (2012). Social working memory: Neurocognitive networks and directions for future research**.** *Frontiers in Psychology, 3*, 571. doi: 10.3389/fpsyg.2012.00571. doi: 10.3389/fpsyg.2012.00571

Michel, G. F., Sheu, C., & Brymley, M. R. (2002). Evidence of a right-shift factor affecting infant hand-use preference from 7 to 11 months of age as revealed by latent class analysis. *Developmental Psychobiology, 40*, 1–13. doi: 10.1002/dev.10008

Michel, G. F., Tyler, A. N., Ferre, C., and Sheu, C. (2006). The manifestation of infant hand use preferences when reaching for objects during the seven- to thirteen-month age period. *Developmental Psychobiology, 48*, 436–443. doi: 10.1002/dev.20161

Microsoft. Released 2010. Windows Movie Maker, Version 2.6 America, Microsoft

Microsoft. Released 2010. Windows XP, America, Microsoft

Miller, E.K., & Cohen, J.D. (2001). An Integrative Theory of Prefrontal Cortex Function. *Annual Review of Neuroscience, 24*, 167-202.

Mills, D. L., Coffey-Corina, S., & Neville, H. J. (1997). Language comprehension and cerebral specialization from 13 to 20 months. *Developmental Neuropsychology, 13*, 397–445. doi: 10.1080/87565649709540685

Minagawa-Kawai, Y., Van der Lely, H., Ramus, F., Sato, Y., Mazuka, R., & Dupoux, E. (2010). Optical Brain Imaging Reveals General Auditory and Language-Specific Processing in Early Infant Development. *Cerebral Cortex,* 1-8. doi:10.1093/cercor/bhq082

Molfese, D. L., Wetzel, W. F., & Gill, L. A. (1993). "Known versus unknown word discriminations in 12-month-old human infants: Electrophysiological correlates." *Developmental Neuropsychology, 9*, 241-258. doi: 10.1080/87565649309540555

Moore, G. A., & Calkins, S. D. (2004). Infants' vagal regulation in the still-face paradigm is related to dyadic coordination of mother–infant interaction. *Developmental Psychology, 40*, 1068–1080. doi: 10.1037/0012-1649.40.6.1068

Moore, G. A., Cohn, J. F., & Campbell, S. B. (2001). Infant affective responses to mother's still face at 6 months differentially predict externalizing and internalizing behaviors at 18 months. *Developmental Psychology, 37*, 706–714. doi: 10.1037//0012-1649.37.5.706

Moreau, P., Jolicoeur, P., Lidji, P. & Peretz, I. (2013). Successful measurement of the mismatch negativity despite a concurrent movie soundtrack: reduced amplitude but normal component morphology. *Clinical Neurophysiology, 124*, 2378-2388. doi: 10.1016/j.clinph.2013.05.013

Morton, K., & Johnson, M. H. (1991). Conspec and Conlern: a two-process theory of infant face recognition. *Psychological Review, 98,* 164-181. doi: 10.1037/0033 295X.98.2.164

Moszkowski, R. J., Stack, D. M., Girouard, N., Field, T. M., Hernandez-Reif, M & Diego, M. (2009). Touching behaviours of infants of depressed mothers during normal and perturbed interactions. *Infant Behaviour and Development, 32,* 183-194. doi: 10.1016/j.infbeh.2008.12.009

Mundy, P., Card, J., & Fox, N. (2000). EEG correlates of the development of infant joint attention skills. *Developmental Psychobiology, 36,* 325–338. doi: 10.1002/ (SICI)1098-2302(200005)36:4<325::AID-DEV7>3.3.CO;2-6

Mundy, P., Hogan, A., & Doehring, P. (1996). A preliminary manual for the abridged Early Social Communication Scales. Coral Gables: University of Miami.

Mundy, P., & Newell, L. (2007). Attention, joint attention and social cognition. *Current Directions in Psychological Science, 16*, 269–274. doi: 10.1111/j.1467-8721.2007.00518.x

Mundy, P., & Willoughby, J. (1998). Nonverbal communication, affect, and social emotional development. In A. Wetherby, S. Warren, & J. Reichle (Eds.), *Transitions in prelinguistic communication: Preintentional to intentional and presymbolic to symbolic* (pp 111– 134). Baltimore, MD: Brookes.

Naoi N., Minagawa-Kawai Y., Kobayashi A., Takeuchi K., Nakamura K., Yamamoto J., et al. (2012). Cerebral responses to infant-directed speech and the effect of talker familiarity. *Neuroimage, 59*, 1735–1744. doi: 10.1016/j.neuroimage.2011.07.093

Nazzi, T., Floccia, C., & Bertoncini, J. (1998). Discrimination of pitch contours by neonates. *Infant Behavior and Development*, *21*(4), 779–784. doi: 10.1016/S0163-6383(98)90044-3

Nazzi, T., Jusczyk, P. W., & Johnson, E. K. (2000). Language discrimination by English-learning 5-month-olds: Effects of rhythm and familiarity. *Journal of Memory and Language, 43* (1), 1–19. doi: 10.1006/jmla.2000.2698

Nelson, C, A., & McCleery, J. P. (2008). Use of Event-Related Potentials in the Study of Typical and Atypical Development. *Journal of the American Academy of Child and Adolescent Psychiatry*, *47(11),* 1252-1261. doi: 10.1097/CHI.0b013e318185a6d8

Nicol-Harper, R., Harvey, A. G., & Stein, A.(2007). Interactions between mothers and infants: Impact of maternal anxiety. *Infant Behavioural Development, 30*(1), 161-167. doi: 10.1016/j.infbeh.2006.08.005

Norton, S., Sacker, A., & Done. J. (2012). Further research needed: A comment on Coyne and van Sonderen's call to abandon the Hospital Anxiety and Depression Scale. *Journal of psychosomatic Research, 73* (1), 75-76. doi: 10.1016/j.jpsychores.2012.04.005

O'Connor, T. G., Ben-Shlomo, Y., Heron, J., Golding, J., Adams, D., & Glover, V. (2005). Prenatal anxiety predicts individual differences in cortisol in pre-adolescent children. Biological Psychiatry, 58, 211-217. doi: 10.1016/j.biopsych.2005.03.032

Out, D., Bakermans-Kranenburg, M.J., & Van IJzendoorn, M.H. (2009). The role of disconnected and extremely insensitive parenting in the development of disorganized attachment: Validation of a new measure. *Attachment & Human Development, 11*, 419-443. doi: 10.1080/14616730903132289

Pallant, J. (2013). *SPSS Survival Manual (5th Ed)*. New York: Open University Press.

Pang, E. W., Edmonds, G. E., Desjardins, R., Khan, S. C., Trainor, L. J., & Taylor, M. J. (1998). Mismatch negativity to speech stimuli in 8-month-old infants and adults. *International Journal of Psychophysiology, 29,* 227.236. doi: 10.1016/S0167-8760(98)00018-X

Parise, E., & Csibra, G. (2012). Electrophysiological Eviden for the Understanding of Maternal Speech by 9-Month-Old Infants. *Psychological Science, 23*, 728-733. doi: 10.1177/0956797612438734

Pascalis, O., de Schonen, S., Morton, J., Deruelle, C., & Fabre-Grenet, M. (1995). Mother's face recognition in neonates: a replication and an extension. *Infant Behavior and Development, 17*, 79–85. doi: 10.1016/0163-6383(95)90009-8

Pegg, J. E., Werker, J. F., & McLeod, P. J. (1992). Preference for infant-directed over adult-directed speech: Evidence from 7-week-old infants. *Infant Behavior and Development, 15*, 325–345. doi: 10.1016/0163-6383(92)80003-D

Peláez-Nogueras, M., Field, T. M., Hossain, Z., & Pickens, J. (1996). Depressed mothers' touching increases infants' positive affect and attention in still-face interactions. *Child Development, 67*, 1780–1792. doi: 10.2307/1131731

Pena, M., Maki, A., Kovacic, D., Dehaene-Lambertz, G., Koizumi, H., Bouquet, F., et al. (2003).Sounds and silence: An optical topography study of language recognition at birth. *Proceedings of the National Acadamy of Sciences, 100*(20), 11702–11705. doi: 10.1073/pnas.1934290100

Polka, L., & Bohn, O. S. (2003). Asymmetries in vowel perception. *Speech Communication, 41*(1), 221–231. doi: 10.1016/S0167-6393(02)00105-X

Price, C. J. (2010). The anatomy of language: a review of 100 fMRI studies published in 2009. *Annals of the New York Academy of Sciences, 1191*, 62–88. doi: 10.1111/j.1749-6632.2010.05444.x

Quinn, P. C., Uttley, L., Lee, K., Gibson, A., Smith, M., Slater, A. M., & Pascalis, O. (2008). Infant preference for female faces occurs for same-but not other-race faces. *Journal of Neuropsychology, 2*, 15-26. doi:10.1348/174866407X231029

Quinn , P. C., Yahr, J., Kuhn , A., Slater, A. M., & Pascalis, O. (2002). Representation of t he gender of human faces by infants: a preference for female. *Perception, 31,* 1109–1121. doi: 10.1068/p3331

Radloff, L. S. (1977). The CES-D Scale: A self-report depression scale for research in the *general population. Applied Psychological Measurement, 1(3), 385-401.*

Raine, A., & Yang,Y. (2006). Neural foundations to moral reasoning and antisocial behavior. *Social, Cognitive, and Affective Neuroscience, 1*, 203–213. doi: 10.1093/scan/nsl033

Reite, M., Short, R., Seller, C., & Pauley, J. D. (1981). Attachment, loss and depression. Journal of Child Psychology and Psychiatry, 22, 141-169. doi: 10.1111/j.1469-7610.1981.tb00539.x

Rosenblum, K. L., McDonough, S., Muzik, M., Miller, A., & Sameroff, A. (2002). Maternal representations of the infant: Associations with infant response to the Still Face. *Child Development, 73*, 999–1015. doi: 10.1111/1467-8624.00453

Rothbart, M. K., & Derryberry, D. (1981). Development of individual differences in temperament. In M. E. Lamb & A. L. Brown (Eds). *Advances in developmental psychology* (Vol. 1, pp 37-86). Hillsdale, NJ: Lawrence Elbraum Associates.

Rowe, J. B., Toni, I., Josephs, 0., et al. (2000). The prefrontal cortex: Response selection or maintenance within working memory? *Science, 288* (5471), 1656–1660. doi: 10.1109/SSBI.2002.1233973

Rushworth, M.F.S., Noonan, M.P., Boorman,E.D.,Walton,M.E.,& Behrens, T. E. (2011). Frontal cortex and reward-guided learning and decision-making, *Neuron, 70*, 1054-1069. doi: 10.1016/j.neuron.2011.05.014

Samples, J. M., & Franklin, B. (1978). Behavioral responses in 7 to 9 month old infants to speech and non-speech stimuli. *Journal of Auditory Research*, *18*(2), 115–123.

Scharoun, S. M., & Bryden, P. J. (2014). Hand preference, performance abilities, and hand selection in children. *Frontiers in Psychology, 5*, 82. doi: 10.3389/fpsyg.2014.00082

Schmidt, L. A., & Trainor, L. J. (2001). Frontal brain electrical activity (EEG) distinguishes valence and intensity of musical emotion. *Cognition and Emotion, 15* (4), 487-500. doi: 10.1080/02699930126048

Scott, S. J., & Wise, R. J. S. (2002). The functional neuroanatomy of prelexical processing in speech perception. *Cognition, 92*, 13 – 45. doi: 10.1016/j.cognition.2002.12.002

Shultz, S., & Vouloumanos, A. (2010). Three-month olds prefer speech to other naturally occurring sounds. *Language Learning and Development*, *6*(4), 241-257.

Singer, L. T., & Zeskind, S. P. (2001). *Biobehavioural Assessment of the Infant*. New York: Guilford Publications.

Singh, L., Morgan, J.L. and Best, C.T. (2002) 'Infants' Listening Preferences: Babytalk or Happy Talk?' *Infancy, 3*, 365–94.

Simiona, F., Macchi Cassia, V., Turatia, C., & Valenzaa, E. (2001). The Origins of Face Perception: Specific Versus Non-specific Mechanisms. *Infant and Child Development, 10,* 59-65. doi: 10.1002/icd.247

Slaughter, V., Heron, M., & Sim, S. (2002). Development of preferences for the human body shape in infancy. *Cognition, 85*, 71-81. doi: 10.1016/S0010-0277(02)00111-7

Smith, S.J. M. (2005). EEG in the diagnosis, classification, and management of patients with epilepsy. *Journal of Neurology, Neurosurgery and Psychiatry, 76*, 2-7. doi:10.1136/jnnp.2005.069245

Snaith, R. P. (2003). The hospital anxiety and depression scale. *Health and Quality of Life Outcomes*, *1*, 29. doi: 10.1186/1477-7525-1-29

Snow, C. E. (1999). Social perspectives on the emergence of language. In B. MacWhinney (Ed.), *The emergence of language* (pp. 257–276). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Spence, M., & DeCasper, A. J. (1987). Prenatal experience with low-frequency maternal-voice sounds influence neonatal perception of maternal voice samples. *Infant Behavior and Development*, *10,* 133-142. doi: 10.1016/0163-6383(87)90028-2

Spielberger, C. D. (1983). *Manual for the State-Trait Anxiety Inventory (Form Y)*. Palo Alto, CA: Consulting Psychologists Press.

Srinivasan R, Nunez PL, Tucker DM, Silberstein RB, Cadusch PJ (1996). Spatial sampling and filtering of EEG with splinelaplacians to estimate cortical potentials. *Brain Topography, 8*, 355-66.

Stanley, C., Murray, L., & Stein, A. (2004). The effect of postnatal depression on mother–infant interaction, infant response to the still-face perturbation, and performance on an instrumental learning task. *Development and Psychopathology, 16*, 1–18. doi: 10.1017/S0954579404044384

Stein, A., Craske, M. G., Lehtonen, A., Harvey, A., Savage-McGlynn, E., Davies, B., et al. (2012). Maternal cognitions and mother–infant interaction in postnatal depression and generalized anxiety disorder. *Journal of Abnormal Psychology, 121*(4), 795-809. doi: 10.1037/a0026847

Stets, M., Stahl, D., & Reid, V. (2012). A meta-analysis investigating factors underlying attrition rates in infant ERP studies. *Developmental Neuropsychology, 37*(5), 226-252. doi: 10.1080/87565641.2012.654867

Stifter, C. A., Coulehan, C. M., & Fish, M. (1993). Linking employment to attachment: The mediating effects of maternal separation anxiety and interactive behavior. *Child Development, 64,* 1451-1460. doi: 10.2307/1131545

Sussman, E. S., Chen, S., Sussman-Fort, J., & Dinces, E. (2013). The Five Myths of MMN: Redefining How to Use MMN in Basic and Clinical Research. *Brain Topography, 27* (4), 553-564. doi: 10.1007/s10548-013-0326-6

Tarabulsy, G. M., Provost, M. A., Deslandes, J., St-Laurent, D., Moss, E., Lemelin, J. P., et al (2003). Individual differences in infant still-face response at 6 months. *Infant Behavior & Development, 26*, 421–438. doi: 10.1016/S0163-6383(03)00039-0

Tarullo, A. R., & Gunnar, M. (2006). Child maltreatment and the developing HPA axis. *Hormones and Behaviour, 50*, 632-639. doi: 10.1016/j.yhbeh.2006.06.010

Techsmith. Released 2010. Snagit, Version 10.0.0 America, Techsmith.

Thibodeau, R., Jorgensen, R. S., & Sangmoon, K. (2006). Depression, Anxiety and Resting Frontal EEG Asymmetry: A Meta-Analytic Review. *Journal of Abnormal Psychology, 115* (4)*,* 715-729. doi: 10.1037/0021-843X.115.4.715

Tian, T. S. & Li, Z. (2011). A spatio-temporal solution for the EEG/MEG inverse problem using group penalization methods. *Statistics and Its Interface, 4,* 521-533. doi: 10.4310/SII.2011.v4.n4.a10

Tronick, E., Als, H., Adamson, L., Wise, S., & Brazelton, T. B. (1978). Infants response to entrapment between contradictory messages in face-to-face interaction. J*ournal of the American Academy of Child and Adolescent Psychiatry, 17,* 1–13. doi: 10.1016/S0002-7138(09)62273-1

Tronick, E. Z., & Cohn, J. F. (1989). Infant-mother face-to-face interaction: Age and gender differences in coordination and the occurrence of miscoordination. *Child Development, 60,* 85-92. doi: 10.1111/j.1467-8624.1989.tb02698.x

Tronick, E., & Weinberg, M. K. (2000). Gender differences and their relation to maternal depression. Paper presented at 15th Symposium on Stress, Coping, and Depression in Miami.

Tucker, D. M. (1993). Spatial sampling of head electrical fields: The geodesic sensor net. *Electroencephalography and Clinical Neurology, 87(3)*, 154-163. doi: 10.1016/0013-4694(93)90121-B

Tzourio-Mazoyer N., De Schonen S., Crivello F., Reutter B., Aujard, Y., & Mazoyer B. (2002). Neural correlates of woman face processing by 2-month-old infants. *Neuroimage, 15*, 454–461. doi: 10.1006/nimg.2001.0979

Ululap, S. O., Biswal, B. B., Yetkin, F. Z., & Kidder, T. M. (1998). Functional magnetic resonance imaging of auditory cortex in children. *Laryngoscope, 108,* 1782-1786. doi: 10.1097/00005537-199812000-00004

Valenza, E., Simion, F., Macchi Cassia, V., & Umilta, C. (1996). Face preference at birth. *Journal of Experimental Psychology*: *Human Perception and Performance,* 22, 892–903. doi: 10.1037//0096-1523.22.4.892

Vouloumanos, A., & Werker, J. F. (2004). Tuned to the signal: the privileged status of speech for young infants. *Developmental Science, 7*(3), 270. doi: 10.1111/j.1467-7687.2004.00345.x

Vouloumanos, A., & Werker, J. F. (2007). Listening to language at birth: Evidence for a bias for speech in neonates. *Developmental Science, 10*, 159-164. doi: 10.1111/j.1467-7687.2007.00549.x

Wager, T. D., Phan, K. L., Liberzon, I., & Taylor, S. F. (2003). Valence, gender, and lateralization of functional brain anatomy in emotion: a meta-analysis of findings from neuroimaging. *Neuroimage, 19*, 513–531. doi: 10.1016/S1053-8119(03)00078-8

Wallis, J. D., & Miller, E.K. (2003). From rule to response: neuronal processes in the premotor and prefrontal cortex. *Journal of Neurophysiology, 90,* 1790-1806. doi: 10.1152/jn.00086.2003

Wang, J., Aguirre, G. K., Kimberg, D. Y., Roc, A. C., Li, L., & Detre, J. A. (2003). Arterial spin labeling perfusion fMRI with very low task frequency. *Magnetic Resonance in Medicine, 49*, 796–802. doi: 10.1002/mrm.10437

Warren, S. L., Gunnar, M. R., Kagan, J., Anders, T. F., Simmens, S. J., Rones, M., et al. (2003). Maternal panic disorder: Infant temperament, neurophysiology, and parenting behaviors. *Journal of the American Academy of Child and Adolescent Psychiatry, 42*, 814-825. doi: 10.1097/01.CHI.0000046872.56865.02

Waters-Wood, S. M., Xiao, L., Denburg, N. L., Hernandez, M., & Bechara A. (2012). Failure to learn from repeated mistakes: persistent decision-making impairment as measured by the iowa gambling task in patients with ventromedial prefrontal cortex lesions. *Journal of International Neuropsychological Society,18*, 927–930. doi: 10.1017/S135561771200063X.

Weinberg, M. K., Olson, K. L., Beeghly, M., & Tronick, E. Z. (2006). Making up is hard to do, especially for mothers with high levels of depressive symptoms and their infant sons. *Journal of Child Psychology and Psychiatry, 47*, 670–683.

Weinberg, M.K., Beeghly, M., Olson, K.L., & Tronick, E.Z. (2008). Effects of maternal depression and panic disorder on mother-infant interaction in the Face-to-Face Still-face paradigm. *Infant Mental Health Journal, 29 (5)*, 472-491. doi: 10.1002/imhj.20193

Weinberg, M. K., & Tronick, E. Z. (1996). Infant affective reactions to the resumption of maternal interaction after the still-face. *Child Development, 67*, 905–914. doi: 10.2307/1131869

Weinberg, K. M., & Tronick, E. Z. (1998). Emotional Characteristics of Infants Associated with Maternal Depression and Anxiety. *Pediatrics, 102* (5)*,* 1298-1304.

Wheeler, R. E., Davidson, R. J., & Tomarken, A. J. (1993). Frontal brain asymmetry and emotional reactivity: A biological substrate of affective style. *Psychophysiology, 30,* 82-89. doi: 10.1111/j.1469-8986.1993.tb03207.x

Woodward A. (2009). Infants 'Grasp of Others' intentions. *Current Directions in Psychological Science. 18*, 537–557. doi: 10.1111/j.1467-8721.2009.01605.x. doi: 10.1111/j.1467-8721.2009.01605.x

Young, E. A., Lopez, J. F., Murphy-Weinberg, V., wastson, S. J., & Akil, H. (2000). Hormonal evidence for altered responsiveness to social stress in major depression. *Neuropsychopharmacology, 23*, 411-418. doi: 10.1016/S0893-133X(00)00129-9

Zigmond, A. S., & Snaith, R. P. (1983). The Hospital Anxiety and Depression Scale. *Acta Psychiatrica Scandinavica, 67* (6)*,* 361,370.

Zimmerman, M., & Mattia, J. I. (1999). The reliability and validity of a screening questionnaire for 14 DSM-IV Axis I disorder (The Psychiatric Diagnostic Screening Questionnaire). J*ournal of Clinical Psychiatry, 60*, 677–683. doi: 10.4088/JCP.v60n1006

Zimmerman, M., & Mattia, J. I. (2001). The Psychiatric Diagnostic Screening Questionnaire: Development, reliability and validity. *Comprehensive Psychiatry, 42*, 175–189. doi: 10.1053/comp.2001.23126