The Effects of the Early Parent-Infant Relationship on Infants' Neural Processing of Emotion

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Declaration

I, Samantha Taylor-Colls, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Signature:

Abstract

This doctoral dissertation provides novel data on the association between the early parent-infant relationship and infants' neurological processing of emotion in non-clinical families. This thesis examines four main contributors to the parent-infant relationship; infant temperament, parental mental health, parental sensitivity and infant attachment in relation to infants' neurological responses to emotional faces as indexed by electroencephalography (EEG) data. All four dimensions of the parent-infant relationship are analysed in relation to infants' Event Related Potentials (ERPs) from EEG data while viewing positive, negative and neutral emotional faces. Three infant face and emotion sensitive ERP components were identified; N290, P400 and the Negative Central (Nc). Maternal mental health, specifically anxiety and depression can be observed to relate to the processing of positive emotion for the early 'face-sensitive' ERP component the N290 and the 'emotion-sensitive' ERP component the Nc respectively. Further yet, parental behaviour, in particular sensitive caregiving, is associated with the neural processing of positive emotion at the most highly studied infant ERP component, the Nc. Infants' neural processing of negative emotion appears sensitive to elements of infant temperament, specifically self-regulatory traits. Infants' attachment to their primary caregiver appears unrelated to infants' ERP responses to emotion. The results are discussed in relation to their theoretical implications for ERP and parent-infant research and the clinical implications associated with emotion processing difficulties.

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1 The Parent-Infant Relationship and its Neurological Imprint

1.1 Introduction:

Infants are born with a set of socially adaptive skills designed to initiate care and ultimately promote their survival. A complex set of innate behaviours such as orienting towards faces, crying and feeding are designed to signal to the parent to provide necessary care and protection (Bowlby, 1958; Sroufe & Waters, 1977). These innate mechanisms are conveniently timed to coincide with a host of neuroendocrine changes that occur in the mother after birth that prime her to receive such signals, ultimately optimising the infant's survival and development (Strathearn, 2011). These appropriately timed evolutionarily adaptive processes from both the parent and child are considered to play a vital role in the development of their relationship and it is now widely accepted that this early relationship plays an important role in an individual's life trajectory (Bokhorst et al., 2003; Bowlby, 1958, 1982; Bretherton & Munholland, 2008; Lyons-Ruth & Jacobvitz, 2008; Schore, 1997, 2001, 2002; Siegel, 2001; Strathearn, Fonagy, Amico, & Montague, 2009; Swain, Lorberbaum, Kose, & Strathearn, 2007). More than six decades of research have given credence to the view that the early experiences an infant has with a primary caregiver shapes their psychological development with particular influence in the domains of social and emotional development (Belsky & Fearon, 2002; Kertz, Smith, Chapman, & Woodruff-Borden, 2008; Mäntymaa, Puura, Luoma, Salmelin, & Tamminen, 2004; NICHD Early Child Care Research Network, 1999; Sroufe, 2005; Zhou et al., 2002). This view not only has substantial empirical evidence to support it at a behavioural level, but can now also be indexed at a neurobiological level as well (Bokhorst, et al., 2003; Gunnar, Brodersen, Nachmias, Buss, & Rigatuso, 1996; Lyons-Ruth & Jacobvitz, 2008; McCrory, De Brito, & Viding, 2012; Pollak, Cicchetti, Klorman, & Brumaghim, 1997; Schore, 1997, 2001, 2002; Siegel, 2001; Strathearn, et al., 2009; Swain, et al., 2007; Tottenham & Sheridan, 2009).

As such, to begin with this chapter will provide an overview of the parent-infant relationship, primarily drawing from attachment theory. Attachment theory is the most widely recognised construct for understanding the nature and development of parent-infant relationships and as such, provides the richest research base regarding its developmental impact. This will then be followed by a review of the literature looking at the impact that parent-infant relationships may have on offspring brain development, ending with a specific focus on the neural mechanisms involved in emotional development.

1.2 The Parent- Infant Relationship and Attachment

The continued existence of a species is determined by the survival of its young. A combination of parental protection and an infant's desire to seek proximity ensure the young do not succumb to environmental dangers, such as predators and starvation. In 1969 the renowned theorist John Bowlby incorporated this ethological thinking into the conceptualisation of his attachment theory in human infants. A young defenceless child who is able to seek adult assistance, especially at times of heightened stress or danger, is more likely not only to survive but also to reap psychological and intellectual benefits thereof. The infant does not act alone in this strategy for survival but rather it is a joint effort from both parent and child. The parent's ability to be consistently available and to provide protection and nurturance is what promotes the child's selective attachment to their caregivers, who then become the target of the child's bid for proximity, ultimately ensuring their young's survival and, it is assumed, more optimal regulation of emotions. As such, a reciprocal interplay of both parent-led and infant-led behaviours contribute to the operation of a behavioural system that maintains the child's safety and feelings of comfort when faced with a range of stressors (Bowlby, 1969).

Alongside this ethological thinking, Bowlby incorporated into attachment theory a psychoanalytic perspective. He posited that not only would this early parent-infant relationship promote survival and developmental advantages but that early attachment relationships would form a template of the individual's relational functioning in later life. In particular, through this early relationship Bowlby argued that an infant develops an internal working model that is carried forward over time and shapes the child's understanding of and responses within close relationships that will endure through the lifespan. These working models ultimately influence the child's growing self perception and representations of others (Bowlby, 1958). Currently, attachment theory provides us with an understanding of some critical aspects of early parent –infant relationships and is key subfield of research looking at the developmental consequences of early childhood experiences. There is now considerable evidence that early attachment to a caregiver influences emotional and social development through childhood and in to adulthood (Belsky & Fearon, 2002; Kertz, et al., 2008; Mäntymaa, et al., 2004; NICHD Early Child Care Research Network, 1999; Sroufe, 2005; Zhou, et al., 2002) .

The organisation of the attachment-based behaviours and individual differences in such behaviours have generated a great deal of empirical research and theoretical innovations. Mary Ainsworth was at the forefront of the early empirical and theoretical work on attachment and worked closely in collaboration with Bowlby. Ainsworth's (Ainsworth, 1967; Ainsworth & Wittig, 1969) revolutionary secure-base concept suggested that there are varying degrees of security for the infant within their relationship to the caregiver. Most importantly, this security is based on prior experience of parental care, i.e a parent who provides sensitive and responsive care will be likely to produce a relationship that provides the infant with feelings of security. According to Ainsworth, and elaborated by others since, it is the infant's level of confidence in the availability of the caregiver and the quality of care they receive that ultimately determines how the attachment system is organised. It is generally believed that insecure attachment relationships place individuals at psychological risk for social and emotional dysfunction as well as impacting on future attachment relationships, including relationships with their own offspring (Cassidy & Berlin, 1994; Grossmann, Grossmann, Winter, & Zimmermann, 2002; Sroufe, 2005) and the evidence broadly supports this view (McElewain, Cox, Burchinal, & Macfie, 2003; Raby, Steele, Carlson, & Sroufe, 2015; Warren, Huston, Egeland, & Sroufe, 1997).

1.2.1 Internal Working Models:

Attachment security is thus thought to have important consequences for the development of representations that capture how one mentally represents the social world, and the self within it. A key legacy of Bowlby's work was the articulation of a concept for understanding how these social representations interact with later socialisation - termed 'internal working models (IWM)'. This psychoanalytic and cognitively derived concept outlined how an infant's repeated exposure to parental care resulted in the development of a mental (cognitive-affective) framework by which social interactions are attended to, interpreted and responded to. Theoretically, IWMs are mental representations of the self, others and the social world. Within them they hold beliefs, memories, emotions and expectations (Bowlby, 1973) concerning attachment related experiences. It is these IWMs that are engaged and activated during social interactions allowing one to predict, interpret and respond to the behaviour of others. IWMs are therefore a form of a mental map that an individual uses to navigate their way through social encounters (Thompson, 2013). Attachment theorists suggest that it is these internalised representations, stemming from secure or insecure attachments, that provide a filter through which other social relationships are interpreted in later life (Bowlby, 1973; Bretherton & Munholland, 2008). For example, a child who has developed a secure attachment will assume they are worthy of love and care and expect others to respond positively towards them, thereby supporting the development of healthy relationships. At the same time, an individual who has developed an insecure relationship may expect new relationships to be unreliable, leaving them to become distant from that individual and thus reinforcing their beliefs. Consequently, close relationship with peers, romantic partners, and one's own children are all thought to be judged in ways that are consistent with the expectations they hold in pre-existing working models of relationships (Bretherton & Munholland, 2008). These models then set up social interactions that are consistent with them, which reinforces and stabilises them over time.

Despite the assumed stability of IWMs, it is also expected that they are partially malleable. The foundations are laid down in early infancy but are subject to growth and alteration based on a myriad of subsequent factors, including cognitive development and environmental changes (Thompson, 2013). Continuity in care across childhood is fundamental in reinforcing and elaborating existing working models and related attachment behaviours into adulthood, alongside biological and environmental changes.

1.2.2 Assessing Infant Attachment Behaviour

A key legacy in Mary Ainsworth's pioneering work in attachment is that of the laboratory based assessment for classifying infant attachment behaviour – The Strange Situation Procedure (SSP; Ainsworth, Blehar, Waters, & Wall, 1978). Ainsworth developed the assessment to assess the balance between exploratory and attachment behaviours during heightened stress (Ainsworth, et al., 1978). Since the establishment of the procedure, the Strange Situation has become the 'gold standard' in assessing an infant's behavioural response to their caregiver in an attachment context. Through a series of reunions and separations with a caregiver (and at times in the presence of a 'stranger'), an infant's behaviour is categorised to reflect a particular attachment pattern. Specifically, the Strange Situation consists of eight episodes (see Table 1.1) designed to slowly induce an increasing level of mild stress in the infant, provoking the attachment system into activation. During reunion episodes the infant's attachment status should manifest itself in particular organised behaviours that are specific to maximising caregiver availability (Main, 1990). Three main classifications of organised behaviour emerge from the Strange Situation; secure, avoidant and resistant attachment.

> *Secure* attachment is marked by behaviours that promote proximity and contact to the caregiver. Typically, secure infants will engage with the 'stranger' and play freely while the caregiver is in the room but will become distressed when the caregiver leaves. Most characteristically, upon reunion secure infants will promptly seek contact and comfort from the caregiver and will typically sooth relatively easily followed by continued exploration.
>
> *Insecure avoidan*ce is characterised by active avoidance of contact with the caregiver during reunion. Avoidant infants tend to explore and play less and are defined by their lack of acknowledgment of and contact with the caregiver during reunions. Contact and proximity to the caregiver is minimal.
>
> *Insecure resistance* is characterised by a behavioural resistance to comfort/contact from the parent. Typically, resistant infants are distressed during separations from their caregiver. Yet on return, a combination of proximity seeking behaviours alongside anger towards the caregiver is evident. Comfort from the caregiver is typically not obtained resulting in a lack of exploration and return to play, and extended distress.

A fourth category of attachment was introduced a decade on from the original Ainsworth classification system, *disorganised attachment* (Main & Solomon, 1986). The emergence of this category was the result of an intensive review of cases by Main and Solomon that found a distinct proportion (15% - Main & Solomon, 1986) of infants displayed behaviours that fell outside of Ainsworth's original classification system.

> *Disorganised* infants are defined by a lack of organised behaviour when reunited with their caregiver after a period of separation. Contradictory, odd and anomalous behaviours are present, such as freezing, incomplete/interrupted movements and frightened behaviour.

Table 1-1 Strange Situation Procedure

Episode	Duration (minutes)	Description
1 • Parent • Infant • Researcher	1	Researcher introduces parent and infant to room and instructs parent to take a seat
2 • Parent • Infant	3	Parent sits and reads a magazine, infant plays with toys. Parent can respond as usual
3 • Parent • Infant • Stranger	3	Stranger enters and sits quietly on other chair for one minute. Stranger talks to parent for 1 minute. Stranger interacts with infant for 1 minute

4 • Infant • Stranger	3 (reduced if infant distressed)	Parent leaves the room. Stranger comforts child if needed, if not needed minimal interaction to infant
5 • Infant • Parent	3	Parent returns, greets infant as normally would. If infant is comforted and returns to play parent is instructed to have minimal interaction
6 • Infant	3 (reduced if infant distressed)	Parent says 'good-bye' and exits the room. Infant is left alone
7 • Infant • Stranger	3 (reduced if infant distressed)	Stranger enters the room and responds to infant if needed. Again, if not needed minimal interaction is maintained
8 • Infant • Parent	3	Parent returns, greets and picks up infant. Parent instructed to responds as normal

In middle class samples the distribution of attachment security is as follows: on average, 62% are classified as secure; 9-10% as resistant; 15% as avoidant; 14-15% as disorganised. In clinical samples the portion of insecure and disorganised attachments are higher (van IJzendoorn, Scheungel, & Bakermanns-Kranenburg, 1999).

Table 1-2 Strange Situation Distribution

Attachment Classification	Observed Strange Situation Behaviour	Percentage (%)
Secure (B) Organised	• May or may not be upset by separation • Acknowledges parents return and	62%

	seeks contact • Soothed by parent and return to exploration	
Insecure – Avoidant (A) Organised	• Unlikely to cry during separation • Does not acknowledge parents return • Turns away or directs parent away in response to parents bids	15%
Insecure – Resistant (C) Organised	• Typically upset when separated • Combined anger displays and contact seeking • Typically not soothed by parent	9-10%
Disorganised (D)	• May or may not be upset after separation • Contradictory/anomalous behaviours • May appear frightened	14-15%

Immediately following the inception of the SSP, Waters (1978) showed that attachment classifications remained stable over time in repeated Strange Situation assessments. Since then, studies of the stability of the Strange Situation have had varied results with effect sizes ranging from small to large (Bar-Haim, Sutton, Fox, & Marvin, 2000; Egeland & Farber, 1984; Frodi, Grolnick, & Bridges, 1985; Goossens, Van IJzendoorn, Tavecchio, & Kroonenberg, 1986; Main & Weston, 1981). It has been argued that the methodological difficulties that arise when measuring a psychological concept, such as attachment, in developmentally appropriate ways across childhood makes validating the Strange Situation more complicated (Thompson, 2013). Furthermore, variations in socio-demographic factors in the populations tested can be seen to contribute to the complexities of validating the Strange Situation.

Although the Strange Situation is considered the ‘gold standard’ attachment assessment for infant attachment research there are, however, alternatives assessments that can be used that have been validated. The Attachment Q-sort (E. Waters & Deane, 1985) is a home-based assessment of attachment which involves matching descriptive statements of behaviour to observed behaviour seen in the home of the child. Different groups of statements are then related to attachment classifications on a continuum based on expert ratings. The advantage of the Q-sort assessment lies in its broad age range but is limited by its need for lengthy observations, a lack of a disorganised scale and the complexity around establishing inter-rater reliability.

1.3 Precursors to the Attachment Relationship

The quality of the attachment relationship formed between parent and child relies on a key number of influential factors. The most important of these factors is parental behaviour, with parental sensitivity thought to be the critical contributing factor in the development of the parent-infant attachment. However, parental behaviour in itself is built on historical predictors of its own, such as previous attachment relationships and parental mental well-being. Below is an overview of how the above mentioned predictors - parental behaviour, intergenerational attachment patterns and parental mental health - contribute in shaping the early attachment relationship.

1.3.1 Parental Sensitivity and Behaviour:

The landmark Baltimore study carried out by Ainsworth and colleagues in 1978 looked at maternal behaviour alongside that of the infants' behaviour. Lengthy home observations of maternal behaviour resulted in the categorisation of four distinct dimensions – sensitivity, acceptance, cooperation and physical/psychological accessibility. It was from these four dimensions that Ainsworth and colleagues were able to reliably predict the infants' attachment pattern in the Strange Situation Procedure. In particular, the infant of a parent who exhibited high scores on all four dimensions was more likely to have a secure attachment pattern than those whose parent scored low across the board. It was, however, maternal sensitivity that was deemed to be most relevant. High levels of maternal sensitivity are indicated when a mother is able to accurately perceive and interpret her infant's cues and consequently respond appropriately and in a timely manner (Ainsworth, et al., 1978).

In more recent years empirical research has not been able to sustain such a robust association between maternal sensitivity and infant attachment status, with a meta-analysis by De Wolff and van IJzendoorn (1997) showing a moderate association between parental sensitivity and infant attachment classification among 21 non-clinical studies. Arguably, this variability in the association between attachment and maternal sensitivity can be viewed in relation to the range of methodological procedures employed to assess parental sensitivity. Differences in coding measures assessing parental sensitivity, as well as varying lengths of observations and various contexts and cultures in which sensitivity is measured, may all contribute to the inconsistent findings. Overall, De Wolff and Van IJzendoorn and another review by Belsky and Fearon (2008) appear to conclude that parental sensitivity is an important but not an exclusive predictor of attachment security. Paternal and non-parental caregiver sensitivity has in some studies shown to be a reliable predictor of security, although weaker than that of maternal sensitivity (Ahnert, Pinquart, & Lamb, 2006; Cox, Owen, Henderson, & Margand, 1992; Goossens & van Ijzendoorn, 1990; Howes & Spieker, 2008). Intervention studies have provided some support for the predictive value of parental sensitivity to attachment classification. Bakerman-Kranenburg et al’s (2003) meta-analysis of intervention studies found a significant improvement, although small, in attachment security after engaging in intervention programs designed to increase parental sensitivity. Similar results have recently been presented in a systematic review and meta-analysis by Mountain and colleagues (Mountain, Cahill, & Thorpe, 2017).

Unsurprisingly, disorganised infant attachment has led to intensive research efforts to identify the distinct parental behaviours that may be accountable for such a disorganised pattern of infant behaviour, outside that of simply insensitive parental behaviour. Two distinct parental styles stand out when associating parental behaviour with disorganisation. The first is maltreatment. Infants who are maltreated are at a heightened risk of being classified as disorganised (V. Carlson, Cicchetti, Barnett, & Braunwald, 1989; Cicchetti, Rogosch, & Toth, 2006). A recent meta analysis highlighted a strong association between maltreatment and attachment disorganisation (d=2.19), relative to high- risk (but not maltreated) children (d=0.48) (Cyr, Euser, Bakermans-Kranenburg, & van IJzendoorn, 2010). The other critical aspect of parental behaviour was identified by Main and Hesse (1990) and is referred to as *Frightened* or *Frightening* (FR) behaviour, as distinct from insensitive care. Empirically, parents who display high levels of anomalous behaviours such as frightening or frightened behaviour appear to place their infants at a significant risk of developing a disorganised attachment (K. Abrams, Rifkin, & Hesse, 2006; Gedaly & Leerkes, 2016; Goldberg, Benoit, Blokland, & Madigan, 2003; Lyons-Ruth, Bronfman, & Parsons, 1999; Schuengel, Bakermans-Kranenburg, & van IJzendoorn, 1999). This is supported by a meta-analysis by Madigan and colleagues (2006) who found a moderate effect size (r = .34) between parents who display anomalous behaviours such as FR as well as other negative parental behaviours such as, affective communication errors, role confusion and dissociative behaviours and disorganised attachment relationships.

1.3.2 Intergenerational Attachment Patterns:

The way in which a parent recalls and represents their childhood experiences has been the primary means by which internal working models of attachment have been measured in adulthood. Thompson (2013) suggests that it is a parent's ability to represent past experience in an open, balanced and meaningful way (regardless of whether childhood memories are negative or positive) that results in a parent being equipped with the psychological resources necessary to promote attachment security. Consistent with that, extensive research has demonstrated that an adult's state of mind with respect to attachment, as measured in the Adult Attachment Interview, is a robust predictor of parent-infant attachment (Hesse, 2008; Main, Kaplan, & Cassidy, 1985; Pederson, Gleason, Moran, & Bento, 1998; van Ijzendoorn, 1995). For example, van IJzendoorn's (1995) meta-analysis showed a large effect size for the association between a parent's state of mind with respect to attachment and their own infant's attachment security (d=1.06).

Attachment theory would suggest that this relationship would be mediated by parental sensitivity but it has been shown that a parent's state of mind in and of itself is a stronger predictor of attachment security than parental sensitivity, with sensitivity only in part mediating this relationship (Pederson, et al., 1998).

1.3.3 Parental Mental Health:

A parent's psychological functioning may have a substantial impact on a parent's behaviour and the care they provide to their offspring. As such, parents experiencing mental health difficulties are more likely to show parenting that is intrusive, withdrawn or is marked by inconsistent displays of affect (Goodman & Gotlib, 1999). The social and emotional effects on child development of parental mental health difficulties are far reaching and have been robustly documented (Cummings & Davies, 1994; Goodman et al., 2011; Murray & Cooper, 1997; Rutter, 1966; Rutter & Quinton, 1984; Smith, 2004).

Maternal depression is one of the most studied clinical disorders in relation to child development. Behaviourally, mothers who are depressed have been found to be less sensitive and contingent in relation to their infant's signals, provide sub-optimal levels of structured play and display more negative affect when interacting with their child (Field et al., 1988; Field et al., 2007; Lovejoy, Graczyk, O'Hare, & Neuman, 2000; Tronick & Reck, 2009). These behavioural manifestations of depression appear to be linked to a range of developmental consequences for offspring. For example, children of parents experiencing depression have been found to have poorer emotion regulation skills (Field, 1992; Tronick & Gianino, 1986; Zahn-Waxler, Iannotti, Cummings, & Denham, 1990), experience greater academic difficulties (Anderson & Hammen, 1993; Hammen & Brennan, 2003; Jaenicke et al., 1987) and experience more behavioural and affective disorders (Biederman et al., 2001; Luoma et al., 2001; Zahn-Waxler, et al., 1990) .

A substantial number of studies have specifically investigated the role of parental (primarily maternal) mental health in relation to infant-parent attachment. For example, mothers of insecurely attached infants obtained lower scores reflecting psychological resilience (as indicated by symptoms of anxiety, depression and neuroticism) than those with infants who were classified as secure (NICHD, 1997).

Although one would expect to see robust associations between parental depression and attachment status and while there is evidence confirming such associations (Campbell, Cohn, Meyers, Ross, & Flanagan, 1993; D'angelo, 1986; Murray, Fiori-Cowley, Hooper, & Cooper, 1996; Teti, Gelfand, Messinger, & Isabella, 1995), there is some research that has failed to find an association (Frankel, Maslin-Cole, & Harmon, 1991; Lyons-Ruth, Zoll, Connell, & Grunebaum, 1986). Meta-analyses highlighted that although small, a significant association exists between parental depression and insecure attachment (r= 0.18, L. Atkinson et al., 2000) but not between parental depression and disorganisation (r= 0.06, van IJzendoorn, et al., 1999).

In regards to disorganisation of attachment, parents diagnosed with a Borderline Personality Disorder (BPD) are more likely to have children classified as disorganised than parents without BPD (Hobson, Patrick, Crandell, Garcia-Perez, & Lee, 2005). A recent systematic review (Eyden, Winsper, Wolke, Broome, & MacCallum, 2016) found that parents with BPD are more likely to interact with their children in a way that is marked by insensitive and hostile caregiving. Furthermore, not only do their offspring have higher rates of disorganised attachment but they are more vulnerable to internalising and externalising problems and emotion deregulation (Eyden, et al., 2016).

Parental psychological well-being may be compromised by environmental stressors independently of any clinical diagnosis. Life stressors associated with socio-demographically disadvantage have been shown to increase the risk of insecure attachments between parents and their infants (van IJzendoorn, et al., 1999). Low income and poverty have been associated with reduced parental sensitivity and higher rates of insecure attachments (Raikes & Thompson, 2005). Furthermore, substance abuse and domestic violence are known to directly influence attachment classification regardless of parental sensitivity (Raikes & Thompson, 2005). Evidence also suggests that cumulative social adversity – in particular multiple indicators of co-occurring and significant disadvantage (e.g., substance abuse, single parent, low income) is associated with a rate of disorganised attachment similar to that of children experiencing abuse (Cyr, et al., 2010).

Marital quality in both middle and lower-income families has also been reported to effect attachment security (Belsky & Fearon, 2008). Thompson (2013) suggests that both the emotional stress that marital conflict creates as well as insensitive care that may arise as a consequence of it both contribute to the development of insecure attachments. Evidence from cross-sectional and longitudinal studies reviewed by Belsky and Fearon (2008) support the view that that marital conflict is associated with a decrease in security.

In summary, attachment security is influenced by a range of factors, from those residing in the social-familial context, to relational and psychological processes residing within the parent. Parental sensitivity is a significant mediator between these social factors and the infant's attachment, although in some cases only partially. Parental frightening/frightened parenting appears to be a key factor in influencing disorganized attachment.

1.4 Developmental Outcomes of the Early Parent-Infant Relationship

Attachment quality has been identified as one of the major influences in healthy psychological growth (Belsky & Fearon, 2002; Kertz, et al., 2008; Mäntymaa, et al., 2004; NICHD Early Child Care Research Network, 1999; Sroufe, 2005; Zhou, et al., 2002). Attachment theorists argue that secure attachment leads to improved later social and emotional functioning. As such, the predictive value of early attachment classifications for later developmental outcomes has been the focus of extensive research. A large number of longitudinal studies have focused on early identified infant attachment and psychological functioning in later childhood and adulthood (Bosquet &

Egeland, 2006; E. Carlson, 1998; Grossman, Grossman, & Waters, 2005; Lyons-Ruth, Dutra, Schuder, & Bianchi, 2006; Sroufe, 2005; Steele & Steele, 2005).

1.4.1 Social Relations:

Bowlby (1979, pg 135) theorized that, "there is a strong causal relationship between an individual's experience with his parents... and his later capacity to make affectional bonds". As such, decades of empirical research has focused on validating this possible causal influence. The evidence appears to support the view that a secure attachment during infancy provides social advantages for a child's subsequent peer relationships.

In particular, secure attachments have been found to be associated with more harmonious and positive peer relationships (Sagi-Schwartz & Aviezer, 2005; Schneider, Atkinson, & Tardif, 2001; Verschueren & Marcoen, 1999) and an increase in the amount of friendships and supportive social networks made in middle childhood (Bost, Vaughn, Washington, Cielinski, & Bradbard, 1998; Elicker, Englund, & Sroufe, 1992; Grossmann & Grossmann, 1991; Lewis & Feiring, 1989). This is further supported by interviewer ratings of child competence in forming friendships when examined in relation to early secure attachment patterns during infancy (Freitag, Belsky, Grossmann, Grossmann, & Scheuerer-Englisch, 1996) as well as securely attached children reporting themselves as less lonely at school age (Raikes & Thompson, 2008).

Furthermore, those classified as securely attached tended to perceive themselves as having successful friendships (Anan & Barnett, 1999; Raikes & Thompson, 2008), have a higher regard for their peers (Berlin & Cassidy, 1999b; Booth-LaForce & Kerns, 2009) and in turn are perceived by peers as being more positive (Bost, et al., 1998). Interestingly, there is evidence that suggests infants who are classified as securely attached tend to form friendships with other children who were also classified as securely attached (Elicker, et al., 1992; Sroufe, Egeland, & Carlson, 1999).

The subgroups of insecure attachments - avoidant and resistant classifications – appear to employ distinct behavioural strategies when interacting with others. Insecure avoidant children have been found to be more aggressive, and actively reject interaction from peers (Cassidy & Berlin, 1994; McElewain, et al., 2003), a behavioural response that can be interpreted to reflect earlier learned coping strategies during infancy, such as emphasizing independence (Berlin, Cassidy, & Appleyard, 2008). On the other hand, resistant children appear to adopt behaviours that are less assertive and more inhibited as well as showing an anxious need to seek positive peer interaction (Cassidy & Berlin, 1994; McElewain, et al., 2003). Again, it has been argued that this social behaviour reflects patterns learned from infancy, where resistant infants display increased levels of vulnerability and neediness (Berlin, et al., 2008). Furthermore, resistant classified children reported higher levels of loneliness than those classified as securely attached (Berlin, Cassidy, & Belsky, 1995).

Considering the above evidence, a meta-analysis by Schneider et al., (2001) on 63 studies only found a moderate to small effect size for the overall relationship between attachment security and peer relationship functioning, $r = 0.20$. Similar findings were also reported in a meta-analysis by Pallini and colleagues (2014) in regards to attachment security and peer relations. Furthermore, a recent meta-analysis by Groh and colleagues(Groh et al., 2014) based on 80 independent samples, found that attachment security was moderately associated with children’s social competence with peers ($d = 0.39$). Specifically, all three subtypes of insecurity were all significantly associated with lower peer competence; avoidance ($d = 0.17$), resistance ($d = 0.29$) and disorganization ($d = 0.25$). As such, the evidence suggests that a secure relationship seems to foster positive behaviours that prove socially advantageous to forming other social relationship in childhood. Insecurity, on the other hand, fosters less adaptive social behaviour, placing the child at greater risk for peer rejection. These important social underpinnings, that develop during infancy, seem to be carried through to adulthood, with infant security predicting relationship security in adulthood (Grossmann, et al., 2002; Roisman, Collins, Sroufe, & Egeland, 2005) .

1.4.2 Psychological Outcomes:

The evidence summarised thus far suggests that a secure base during infancy equips an individual with skills or capacities that are important in dealing with the social world. Underlying those abilities may be a tendency towards greater self-worth, emotional maturity and emotional regulation. These factors may also account for associations between attachment and mental well-being. In line with the evidence regarding attachment and later relationships, early security appears to act as a protective factor in the development of healthy psychological development.

The influential Minnesota Study of Risk & Adaptation from Birth to Adulthood (Bosquet & Egeland, 2006; Sroufe, 2005; Sroufe, Egeland, Carlson, & Collins, 2005; Warren, et al., 1997) highlighted the psychosocial risks related to early attachment security. In their longitudinal data analysis of high-risk families from birth to 28 years old, Sroufe et al. (2005) found that secure attachment during infancy was significantly associated with a range of psychological competencies including self-reliance, emotional regulation and social competence in childhood and adulthood.

Further, in relation to healthy personality development, there is evidence that has shown that the securely attached children described themselves more positively and are seen as more agreeable compared to insecurely attached children, who tend to have a higher negative self-image and more negative self-appraisal (Cassidy, 1988; Colman &

Thompson, 2002; Goodvin, Meyer, Thompson, & Hayes, 2008; Verschueren, Marcoen, & Schoefs, 1996). The impact that the early parent-infant relationship has on an individual's self concept has been shown to carry forward into middle childhood (Cassidy, Ziv, Mehta, & Feeney, 2003). However, it must be noted that not all studies have found this direct link between early attachment patterns and later self-concept (see S. Clark & Symons, 2000).

Insecurity, on the other hand, has been known to place children at risk of later internalising and/or externalising mental health problems (Berlin & Cassidy, 1999a; Booth-LaForce & Kerns, 2009; Fearon, Bakermans-Kranenburg, van IJzendoorn, Lapsley, & Roisman, 2010), albeit with modest effect sizes. Internalising problems, such as depression, withdrawal and anxiety have been shown to have a small but significant association with insecure attachment in two recent meta-analyses. Interestingly, these difficulties are most prevalent in those classified as having an insecure avoidant attachment (Groh, Roisman, van IJzendoorn, Bakermans-Kranenburg, & Fearon, 2012; Madigan, Atkinson, Laurin, & Benoit, 2013). Furthermore, Dallaire and Weinraub (2007) suggested that a secure attachment when measured during infancy provided a protective factor in the development of anxiety related symptoms during preschool years. On the other hand, externalising behavioural problems (i.e. defiance, aggression, antisocial behaviour) in childhood are associated with disorganised attachment ($d = 0.34$) with less robust, but significant, associations with insecure avoidant attachments ($d = 0.12$) and resistant attachments ($d = 0.11$; Fearon, et al., 2010). Comparatively, attachment security is better at predicting externalising problems than internalising problems in relation to both insecure attachment generally (externalising $d= 0.31$ versus internalising $d=0.15$) and disorganised attachment specifically (externalising $d= 0.34$ versus internalising $d=0.08$ Groh, et al., 2012).

The apparently greater risk for externalizing behaviour problems associated with disorganized attachment (Dutra, Bureau, Holmes, Lyubchik, & Lyons-Ruth, 2009; Dutra & Lyons-Ruth, 2005; Kobak, Cassidy, Lyons-Ruth, & Ziv, 2006; Lyons-Ruth, et al., 2006; MacDonald et al., 2008; Ogawa, Sroufe, Weinfield, Carlson, & Egeland, 1997; Sroufe, 2005; Sroufe, et al., 2005) is consistent with theorizing regarding the nature of disorganized attachment. To classify an infant as disorganised during the Strange Situation, an array of ‘unorganised’ behavioural strategies must be displayed by the infant during times of heightened stress, i.e freezing, odd/contradictory behaviours and frightened facial expression. Attachment theorists suggest that these disorganised behaviours stem from the infant’s experience of seeking reassurance and protection from the person who has caused the initial fear. This unsolvable behavioural ‘paradox’ is thought to place the child in a temporary dissociate state, resulting in the disorganised behaviours witnessed during the Strange Situation (Hesse & Main, 2000; Main & Hesse, 1990). It is argued that it is this overwhelming contradictory situation that is imprinted into the IWMs of the infant and consequently relied on during later social situations (Thompson, 2008). This notion that dissociative processes may be central to the vulnerable status of disorganised children is supported by a longitudinal study by Carlson (1998). Carlson (1998) reported that the classification of an infant as disorganised was predictive of teacher-reported dissociative symptoms and behavioural/internalising problems during childhood as well as self-reported dissociative and psychopathological symptoms during adolescence. Furthermore, there is evidence to suggest that early insecurity, specifically disorganisation, is associated with anxiety disorders in adolescence (Warren, et al., 1997).

1.4.3 Emotion Development:

It can be argued that at the very core of these affected developmental outcomes outlined above is the inability to correctly identify, interpret, regulate and respond to emotion. Consequently, and of particular importance for this thesis, a number of studies have investigated the connection between attachment and emotional processing.

Evidence directly relating attachment status to emotion face processing in childhood is limited. There is some evidence that has shown that infants classified as insecure during infancy have greater difficultly in judging happy facial expressions in childhood (Steele, Steele, & Croft, 2008), Furthermore, a very recent study highlighted that insecure infants, as assessed in the Strange Situation, had a smaller attentional bias to fearful faces at 7 months of age (Peltola, Forssman, Puura, van IJzendoorn, & Leppänen, 2015). This finding is particularly intriguing given that it has been robustly demonstrated that at 7 months of age, typically developing infants have a bias towards fearful faces. This threat-related bias can be seen in longer looking times towards fearful faces (Kotsoni, de Haan, & Johnson, 2001; Nakagawa & Sukigara, 2012; Nelson & Dolgin, 1985; Peltola, Hietanen, Forssman, & Leppänen, 2013; Peltola, Leppänen, & Hietanen, 2011; Peltola, Leppänen, Palokangas, & Hietanen, 2008) as well as increased neural responses to fearful face (De Haan, Belsky, Reid, Volein, & Johnson, 2004; Leppänen, Moulson, Vogel-Farley, & Nelson, 2007; Nelson & De Haan, 1996; Peltola, Leppänen, Mäki, & Hietanen, 2009). As such, an absence of this bias associated with insecure attachment is potentially important. Both studies provide useful direct, albeit limited, evidence of an association between infant attachment and emotion processing.

Attachment can be understood as fundamentally an emotion regulation process in that the attachment relationship allows the child to regulate his/her heightened emotional state through contact with a carer. This regulatory or homeostatic function that the relationship affords the child may be an important reason why secure attachment yields social advantages to the child as they grow older, because it facilitates the ability to competently identify and empathise with emotions as well as self-regulate their own emotion (Cassidy, 1994; Thompson, 1994). In that regard, the evidence relating emotion regulation to attachment status is substantial (Braungart & Stifter, 1991; Bridges & Grolnick, 1995; Cassidy, 1994; Diener, Mangelsdorf, McHale, & Frosch, 2002; Leerkes & Wong, 2012; Sroufe, 2005; S. Waters et al., 2010). For example, Gilliom and colleagues (2002) found that early security (and positive maternal control) was positively associated with constructive anger management techniques at 3 ½ years of age for boys. At the same time, emotion dysregulation and inefficient regulation techniques are more frequently observed in insecurely attached children (Braungart & Stifter, 1991; Bridges & Grolnick, 1995; Calkins & Johnson, 1998; Cassidy, 1994; Crugnola et al., 2011; Diener, et al., 2002; Leerkes & Wong, 2012; E. C. Martins, Soares, Martins, Tereno, & Osório, 2012).

In addition, a substantial number of studies have investigated the role of attachment in relation to later emotional understanding. In particular, evidence suggests that those who are securely attached to their parent are more advanced in emotional understanding, exhibiting a greater understanding of negative and mixed feelings compared to insecure children (Denham, Blair, Schmidt, & DeMulder, 2002; Greig & Howe, 2001; Laible & Thompson, 1998; Ontai & Thompson, 2002; Raikes & Thompson, 2006; Rosnay & Harris, 2002; Steele, Steele, Croft, & Fonagy, 1999).

Emotional communication has been argued to be fundamental in the development of emotional understanding (Denham, Zoller, & Couchoud, 1994; Laible, 2004; Ontai & Thompson, 2002). A substantial amount of work has looked at communication between children and their parents in relation to emotion. Pioneering work by Bretherton (1993) draws attention to the importance of open communication in secure parent-infant dyads. Empirically it has been shown that secure dyads tend to have richer conversations about emotions than insecure dyads (Laible, 2004; Laible &

Thompson, 2000; Raikes & Thompson, 2006). The importance of emotion-focused dialogue is supported by Raikes and Thompson (2006) who reported that the quality of mother-child conversation mediated the association between attachment security and emotional understanding in three year olds.

Underpinning the above evidence lies the idea that at the base of a secure relationship there is an openness that allows for communication to arise about developing emotions (Bretherton, 1993; Thompson, 2000). It is suggested that in a secure relationship, the mother is able to develop a child's understanding of their psychological world in which emotions are shared and appreciated between each other as well as with others (Thompson, 2008). Through emotionally open interactions with the caregiver the child learns about human relationships, appreciating and beginning to understand emotion.

1.5 Interim Conclusion

To conclude, the parent-infant attachment relationship is rooted in an evolutionary drive to support the survival and ultimate reproduction of young. It is a process that is driven by a range of parental behaviours, most critical being sensitivity, which, itself, is linked to the parent's own past experiences of attachment and their current state of mind with respect to those experiences. As well as ensuring basic emotional needs are met in infancy and early childhood, attachment has important consequences for later social and emotional development. Behavioural evidence, based on observation or adult-report questionnaires has been the mainstay of this research field and has been imperative for our understanding of the developmental impact of early attachment. However, in recent years, there has been a surge of interest in understanding how early experiences, particularly within caregiving relationships affects the developing brain. However, remarkably little work has investigated the brain processes linked to early caregiving and to attachment security and insecurity. Although still in its infancy, developmental neuroscience has the potential to contribute in important ways to our overall understanding of the effects of the early parent-infant relationship. Together, behavioural and neuroscientific research complement one another, providing the researcher with a choice of tools to assess the developmental effects of early parent-child relationships. Incorporating neuroimaging techniques can provide the researcher with an objective marker of key neural areas and processes that may be relevant for healthy psychological development. It is a technique that is less susceptible to participant bias and is particularly valuable when language is absent, as during infancy. Neuroscientific research is helping bridge these gaps in the literature.

1.6 The Neurological Indexes of the Parent-Infant Relationship

The continuing work focused on assessing the effects of the early parent-infant relationship on an individual's life trajectory has been strengthened by increasing evidence emerging from neuroscientific research regarding the susceptibility of brain development to environmental influence. As Luu and Tucker put it 'To understand neuropsychological development is to confront the fact that the brain is mutable, such that its structural organisation reflects the history of the organism' (Luu & Tucker, 1996, p. 297). It is widely accepted that during infancy the brain undergoes rapid maturation and infancy appears to be a key period of neural plasticity (Johnson, 2001; Johnson et al., 2005). The newborn infant is born with a similar number of neurons as are observed in the adult brain (Nowakowski, 2006). However, through both intrinsic and external inputs, neuronal dendrites and synapses are selectively 'pruned', particularly in the first months of life, resulting in more stable and efficient neurological pathways (Johnson, 2001). Arguably, one of the key factors contributing to this environmental structuring of neural development is the parent-infant relationship. Interactions within a parent-child relationship may guide selective pruning of neural pathways in the developing brain as well as potentially increase neural connections (Belsky & De Haan, 2011). Evidence for this comes from a variety of sources, but particularly compelling data comes from studies of the impact of early adversity of brain development.

1.6.1 Early Adversity and the Developing Brain:

The relationship between the environment and the developing brain has predominantly been investigated by examining brain development in the context of highly adverse circumstances, such as maltreatment or institutional rearing. Both domains of adversity imply highly insensitive or atypical early care, whether it is in the form of physical, sexual or emotional abuse or the extreme neglect associated with institutional environments.

Recent evidence indicates that extreme adversity is related not only to structural differences in brain development but also functional differences in both the developing brain and subsequently the adult brain (Maheu et al., 2010; McCrory, et al., 2012; Rao et al., 2010; Tottenham et al., 2011). Despite the increasing amount of evidence linking a range of brain structures and functioning to exposure to early maltreatment, two neural structures appear to be emerging as critical; the corpus collosum and the hippocampus. The corpus collosum, is a white matter structure involved in hemispheric interconnection, and is also thought relevant for arousal, emotion and high level cognitive-processing (Belsky & De Haan, 2011; McCrory, et al., 2012). The hippocampus, a layered structure belonging to the emotion-related limbic system, plays a key role in memory (Belsky & De Haan, 2011). Converging evidence suggests that there is a marked decrease in hippocampal and corpus collosum volumes for individuals who have experienced childhood maltreatment (Andersen et al., 2008; Bremner et al., 1997; De Bellis et al., 1999; Driessen et al., 2000; Rao, et al., 2010; Teicher et al., 2004). Interestingly, a volume reduction in the hippocampus is only identified during adult assessments and is not present in childhood assessments (De Bellis, Hall, Boring, Frustaci, & Moritz, 2001; De Bellis, et al., 1999). It has been argued that there may be a delay in the impact of the stress that only becomes apparent in later development (for a review see McCrory, et al., 2012).

Adding to the aforementioned evidence is research investigating the association between structure and functioning of the neocortex and past exposure to abuse, although this literature has been less consistent in its findings. Evidence of association between abuse and brain structure and function has been seen in the anterior cingulate, the orbitalfrontal cortex, the dorsolateral prefrontal cortex and both the visual and auditory cortex (McCrory, De Brito, & Viding, 2010) . Moreover, maltreatment is thought to be responsible for smaller intracranial and cerebral volumes and maltreated children tend to have larger lateral ventricular volumes (De Bellis et al., 2002) an association seemingly overlapping with later psychopathology (Brent, Thermenos, Keshavan, & Seidman, 2013). Furthermore, the length of the abuse experienced has been found to be negatively correlated with brain structural size, with males showing more susceptibility to structural reduction than females (De Bellis, et al., 1999; De Bellis, et al., 2002; Teicher, et al., 2004; Teicher et al., 1997). Interestingly, evidence suggesting an association between amygdala volume and childhood adversity is less abundant. One study (Mehta et al., 2009) did, however, suggest that amygdala volumes were greater, particularly over the right hemisphere, in adolescents who had been institutionally reared compared to family reared controls. Mehta found that it was the length of stay in institutional care that was reflected in the amygdala volume size. However, the majority of studies fail to find a robust association between amygdala volumes and early adversity as indicated by reports of maltreatment (Andersen, et al., 2008; Bremner, et al., 1997; De Bellis, et al., 1999). Considering the strong association between the amygdala and its role in detecting and evaluating emotional stimuli (Davis & Whalen, 2001; Whalen & Phelps, 2009), the lack of strong evidence showing a relationship between amygdala volume and past adversity, which is characterized by unpredictable emotional situations, is surprising.

What is of increasing interest is the suggestion that these structural neurological differences appear vulnerable during a developmental time-window. Studies of animals have indicated for some time that there may be sensitive periods during which an individual is more susceptible to lasting structural brain changes as a result of environmental pressure (Gunnar, Hostinar, Sanchez, Tottenham, & Sullivan, 2015). An important study by Anderson and colleagues (2008) yielded evidence that suggested that the hippocampus is more susceptible to volume alteration when abuse was experienced during the age range of 3 - 5 years and 11 – 13 years. An individual's corpus collosum was found to be more vulnerable to change if they were maltreated when they were between the ages of 9 to 10 years. Finally, the prefrontal cortex appeared somewhat more vulnerable when the abuse was experienced in late adolescence (14-16 years).

These findings that could indicate sensitive periods are intriguing in regards to the neural plasticity of the developing brain. As new experiences and learning are continuous, neural plasticity has been considered a process that occurs throughout the course of a lifetime (Pascual-Leone, Amedi, Fregni, & Merabet, 2005). However, at certain times in development the neural circuitry in specific regions in the brain may be more susceptible to environmental influences (Tottenham & Sheridan, 2009). Infancy is considered to be one of the key sensitive periods that is prone to time-limited neural plasticity. However, this is yet to be fully explored at an empirical level, primarily due to the technical and practical issues involved in infant structural imaging.

1.6.2 Early Adversity, Emotion Processing and the Developing Brain

Structural growth and the size of specific brain areas are of importance in a comprehensive understanding of the impact that early experiences have on the developing brain. However, growth alone is limited in its ability to inform us about the functionality of these specific brain areas and how this may then cascade into observable behaviour. The last decade has seen a growth of research assessing the effects that various early life experiences may have on the functionality of the developing brain in relation to social and emotional processing. The backbone of this type of research has been functional imaging studies of maltreated or institutionalised children.

A great deal of research has focused on emotional development, i.e. emotion processing, recognition and/or understanding, and incorporates the use of salient emotional cues such as facial expressions. To date, converging evidence indicates that children who have experienced maltreatment in early life or who have been raised in institutions have neural hyperactivity to negative face stimuli (Maheu, et al., 2010; McCrory et al., 2013; McCrory, De Brito, & Viding, 2011; Tottenham, et al., 2011). In particular, McCrory and colleagues (2013) showed greater right amygdala activation to angry facial expressions among maltreated adolescents. The authors suggest this amygdala bias in activation in response to negative face stimuli is the result of a 'hyper-vigilance' to threat–related situations that reflects a history of experiences in which negative faces were extremely salient. Furthermore, studies using electroencephalography (EEG) to look at the effects of emotion on Event Related Potentials (ERPs - a process described in more detail in chapter 2) in maltreated samples overall suggest greater ERP amplitudes to angry facial expressions (Cicchetti & Curtis, 2005; Pollak, Klorman, Thatcher, & Cicchetti, 2001; Pollak & Tolley-Schell, 2003). The increase in ERP amplitudes to threat-related stimuli is interpreted as an increase in attentional resources. EEG studies thus also indicate a ‘hyper-vigilant’ pattern of neural responses to threat-related cues in children who have a history of maltreatment. Children who have previously been institutionalized have also shown similar neural responses to emotional faces, although in this case it is fearful faces that appear more salient. Specifically, hyperactivity is seen in the amygdala in response to fearful faces compared to children who have never been institutionalized (Tottenham, et al., 2011) as well as an increase in neural amplitudes in response to fearful faces in early face sensitive ERP components for previously institutionalised children (Parker & Nelson, 2005).

Overall, the evidence relating early adversity to brain growth and functioning is mounting. Extreme early experiences during childhood appear to contribute to not only structural growth but the functionality of the developing brain, in particular neural processes and circuitry associated with emotional development. Studies of early adversity, such as maltreatment and institutionalisation, provide a valuable insight into the neurological impact of the environment and of extremes of parenting experiences (or lack thereof) on the developing brain. These empirical investigations, incorporating such adverse populations, highlight the relationship between early experienced environments and neurological development. Much less is known however, about the effects of less extreme variation in parenting and childhood brain development.

1.6.3 Parenting and the Developing Brain

Research looking into the effects of parenting on the developing brain in non-clinical samples is much less abundant than that of atypical populations. Given the extensive evidence that highlights the importance of the parent-infant relationship on child development, it is surprising how little work has been carried out assessing the brain bases of these effects in typically developing populations. Various features or indicators of parenting have however been examined in relation to brain development in a small number of studies.

Recently, Whittle et al. (2014) found larger right amygdala volumes in adolescent males whose parents responded in a harsh and punishing manner to their displays of positive affect during a mother-adolescent interaction. In turn, larger amygdala volumes predicted aggressive behaviour from these adolescents towards their parents in a problem solving task. Furthermore, larger left dorsal anterior cingulate cortex and bilateral orbitofrontal cortex volumes were apparent for males whose mothers presented this pattern of interaction. It has also been found that parental nurturance at age 4 years old was predictive of hippocampal volume at age 14 in a sample of non-clinical children, but this effect was not sustained when nurturance was measured at age 8. This is suggestive of a developmental time-window involved in the maturation of the hippocampus in early childhood (Rao, et al., 2010).

More indirect measures of the parenting environment, such as maternal mental health, have also been shown to effect neurological development. In particular, the effects of maternal depression on neurological functioning have been widely considered in the developmental field. Considerable evidence suggests that infants of depressed mothers exhibit greater relative right frontal EEG activation in the alpha frequency range than infants of non-depressed mothers (e.g., Dawson, Klinger, Panagiotides, Hill, & Spieker, 1992; Jones, Field, & Almeida, 2009). This hemispheric bias has also been seen to reflect distinct parenting interactive styles, with infants of withdrawn depressed parents displaying greater relative right frontal EEG activity than infants of intrusive depressed mothers (Diego et al., 2006; Jones, Field, Davalos, & Pickens, 1997; Jones et al., 1997). Furthermore, children whose mothers have elevated depressive symptoms have been shown to have larger amygdala volumes than those children without a depressed parent (Lupien et al., 2011).

Sub-cortical differences in adult amygdala volumes have also recently been linked to differences in attachment security during infancy. Moutsiana et al. (2014) showed that infants who were classified as insecurely attached during the Strange Situation Procedure at 18 months of age had larger amygdala volumes at 22 years of age compared to those adults who were classified as securely attached during infancy. The authors suggest that this increase in amygdala volume may be a consequence of prolonged and repeated activation of the child's stress response system in response to an insensitive caregiving experience in childhood.

However, the strongest current evidence for *typical* parenting relating to infants' neural functioning comes from Hane & Fox (2006). Hane & Fox found that directly observed parenting insensitivity was associated with greater relative right frontal EEG asymmetry in 9-month old infants.

The above limited research incorporating typically developing human populations is substantially supported by research in non-human samples. In brief, rodent pups who have been exposed to maternal separation or poor maternal care have demonstrated smaller hippocampal volumes (Meaney, 2001) as well as impaired hippocampal functioning (Huot, Plotsky, Lenox, & McNamara, 2002). Furthermore, chronic maternal separation for rodent pups appears to accelerate amygdala maturation (Callaghan & Richardson, 2013; Raineki, Cortés, Belnoue, & Sullivan, 2012).

1.6.4 Parenting, Emotion Processing and the Developing Brain

As previously highlighted, investigations into the effects of parenting on neurological development in offspring in non-clinical samples is very limited.

Furthermore, even less has been done on the influence of parenting on neural systems involved in social and emotional development. This is surprising given the volume of research assessing the contribution that parenting has to offspring social and emotional development.

One study which has attempted to bridge this gap was carried out by De Haan and colleagues (2004). De Haan examined maternal personality as an indirect marker of parenting behaviour in relation to infant ERPs to emotional face stimuli. Results indicated that mothers who were assessed as having high levels of positive affect had infants who displayed greater ERP amplitudes, in a component known as the Negative Central (Nc), to negative faces (fearful expressions) compared to happy facial expressions. However, this finding was only apparent for those infants who themselves had scored high on a dimension of positive temperament. These results led De Haan et al. to conclude that maternal positive affect may lead infants to display diminished neural responses to happy facial expressions, due to their consistent exposure to positive affect in the caregiving environment. Despite the lack of direct observation of parenting, this study is the first to address the role of 'typical' parenting in relation to neurological processes involved in emotion development in infants.

A further study that has shed some light on the effects of parenting on neurological emotional development in infants comes from Diego and colleagues (2006). Although this study incorporates a sample of depressed parents and that in of itself is clinically based, it is vastly different from the 'atypical' populations mentioned previously in regards to severe abuse and privation. As such, parallels are more easily drawn from Diego's study to non-clinical samples. Diego et al. (2006) divided a sample of mothers who were displaying depressive symptoms into two groups with distinct parenting styles; withdrawn and intrusive parents. These infants then experienced a stranger presenting ‘sad’, ‘surprise’ and ‘happy’ facial expressions. Interestingly, infants who experience parents with intrusive parental behaviours displayed greater relative right EEG activation when witnessing the ‘surprised’ and ‘sad’ facial expressions. The infants with a withdrawn parent displayed no marked difference in activation to any facial expressions. This emotion related neurological marker in regards to specific parental styles is extremely valuable in beginning to untangle the influence that parenting (and its myriad of manifestations) has on neurological development in relation to emotion processing.

1.7 Summary:

Converging evidence points to a robust association between the early parent-infant relationship and later social and emotional development (Belsky & Fearon, 2002; Kertz, et al., 2008; Mäntymaa, et al., 2004; NICHD Early Child Care Research Network, 1999; Sroufe, 2005; Zhou, et al., 2002). Impressive longitudinal studies have provided a wealth of evidence relating deficits in socio-emotional functioning back to the early environment between infant and parent. Attachment and the parent-child relationship is influenced by a host of factors, such as parental mental health, environmental stress and previous attachment relationships. The developmental outcomes for the child that stem from this early relationship are evident in an array of social and emotional domains including social relationships, emotion processing, affect regulation and psychopathology. The developmental impact of the parent-infant relationship has led to a surge of interest in finding neural markers of this association. As such, neuroscience has started to explore the consequences of the early caregiving environment in relation to neural structure and functioning.

The evidence emerging from this research suggests that the early environment an infant experiences is significantly related to the development of specific neural structures and to neural functionality. Evidence alludes to role of early adversity in volume modulation of total brain size and hippocampal and corpus collosum volumes (Andersen, et al., 2008; Bremner, et al., 1997; De Bellis, et al., 1999; Driessen, et al., 2000; Rao, et al., 2010; Teicher, et al., 2004). Furthermore, specific neural responses linked to emotion processing such as sub-cortical activation, ERPs and frontal asymmetry have all been shown to relate to early experiences. The majority of the research assessing the neurological imprint associated with early environmental experiences is restricted to adverse populations, with privation and maltreatment being the primary focus of these studies. These research studies have laid the foundation of evidence relating early experiences to neural development and specifically to neural systems involved in emotional and social development. A review of the evidence indicates the need to track this association in typical development. A handful of investigations have started to unpack this association within the realm of typical parenting and have provided some much needed evidence highlighting the effects of early experiences in childhood in relation to neural development. However, what is lacking in the literature is a thorough investigation of typical parenting which includes assessment of observable parenting behaviour in relation to infants' neural development. Furthermore, given the robust associations between parenting and later social and emotional functioning, a specific focus on neural correlates of emotionally relevant stimuli is needed.

As such, this thesis aims to investigate the neural correlates of emotional processing in typically developing infants and test their association with a range of measures indicative of the quality of parent-child relationships. Specifically, four key domains linked to the parent-infant relationship will be explored; infant temperament, parental mental health, parental sensitivity and infant attachment. All four domains will be assessed in relation to infants' electroencephalogram recordings of Event-Related

Potentials to three key facial emotional expressions; fear, happy and neutral. This thesis has the potential to further our understanding of the developmental consequences associated with the early parent-infant relationship. Furthermore, it will provide novel data regarding the effects of parenting on infants' functional neural development.

2 General Methods

2.1 Introduction

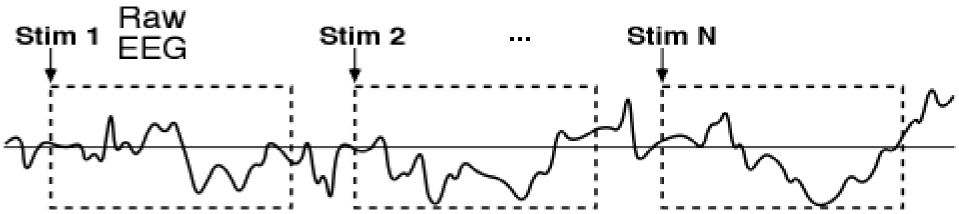
This thesis is an investigation assessing the influence of the early parent-infant relationship on infants' neural processing of emotional facial expressions. Through a series of chapters in this thesis, this overall question was explored with the use of a neuroimaging/electrophysiological technique known as Electroencephalography (EEG). The thesis focuses specifically on consistent neural responses time-locked to visual stimuli, referred to as Event Related Potentials (ERPs). These neural markers were examined in relation to behavioural measures assessing the early caregiving environment. The thesis represents a single longitudinal study, and each chapter presents data arising from this study pertaining to key sub-questions relating to the overall goals of this doctoral thesis. The current chapter provides an overview of the experimental methodology used across all the chapters of this thesis. More detailed information concerning methodological procedures specific to each research question is provided in each relevant chapter.

2.1.1 EEG and Event Related Potentials (ERPs): An Introduction

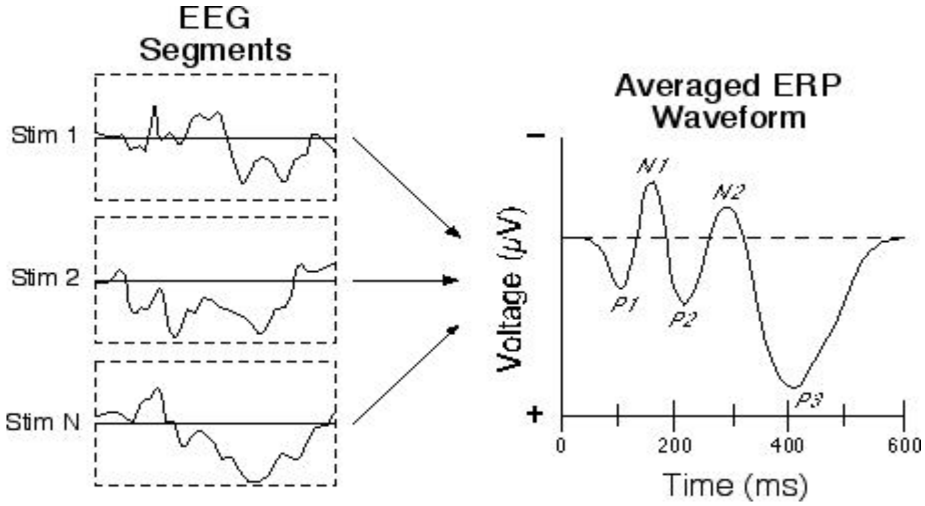
The human EEG that is recordable from the scalp is a reflection of electrical neuronal activity in the brain projected via volume conduction to the scalp. In particular, electrodes placed at the scalp (either individual electrodes or a cap of electrodes) are primarily detecting activity in large pyramidal cells that are mostly seen in the fifth layer of the cortex (Kappenman & Luck, 2012; Luck, 2005). Neurotransmitters, when attaching to receptors on postsynaptic cells of the dendrites of a pyramidal cell, trigger changes in post-synaptic potentials, which result in small recordable electrical dipoles. The length of these postsynaptic potentials, which can extend to hundreds of milliseconds, all contribute to a summated electrical potential projected through the tissues of the brain and skull and are detectable at the scalp (Kirschstein & Köhling, 2009; Luck, 2005).

Within an EEG recording (that is recorded using sensors attached to the scalp of the head) lie numerous neural responses that can be related to a specific cognitive and/or affective process. Although indistinguishable in its raw EEG format, these neuro-cognitive/affective responses can emerge out of EEG data in the form of an Event–Related Potential (ERP). In particular, an ERP is a neurally generated response that is evoked by a particular stimulus or set of stimuli, reflecting specific neural processes (Kappenman & Luck, 2012). To achieve an ERP out of continuous EEG data, a process of time-locking and signal averaging of the data is required. Firstly, an epoch is created by selecting a period of time that is of interest after stimulus presentation (e.g. 600-700 milliseconds long). This epoch is time-locked to the stimuli presentation. This pre-defined epoch is then used to segment the continuous EEG data into numerous epochs. These segments (or epochs) of data are then baseline corrected (so that any difference in means across different epochs are removed) either to the entire length of the segment or to a chosen time period before stimulus presentation (typically 100-200 ms). The result of this process is an individual ERP waveform for each segmented epoch that is time-locked to stimulus onset and equal in length. To derive a reliable index of the consistent response triggered by the stimulus, all these epochs (each consisting of an ERP waveform) are then averaged together to arrive at one single ERP waveform. By ensuring there are sufficient amount of trials per experimental condition noise that is unrelated to the stimulus (movement/electrical interference) can be removed during the averaging process (Luck, 2005). Through this single, averaged ERP waveform neuro-cognitive processes can be assessed in relation to chosen stimuli. See figure 2.1.

Figure 2-1 ERP Averaging Process



A. Continuous EEG segmented into predefined epochs



B. Collated EEG segments to produce an average ERP waveform

The resulting averaged ERP is made up of peaks and troughs (like blips in the waveform) that are either positive or negative deflections from zero and are known as components. ERP components are specific in topography (the area on the head) and latency (the point in time a peak occurs) after stimulus onset, as well as by their functional properties (e.g., experimental conditions they are sensitive to, such as face processing). Numerous EEG investigations have made it possible to identify a range of key components relevant to specific neuro-cognitive processes. These components are typically described either by an acronym such as the Nc- the negative central - or firstly by a letter indicating polarity such as N (negative) or P (positive) and their subsequent ordinal position within the waveform or the time at which they occur, i.e. the P1 which is a the first positive deflection occurring in the waveform. See figure 2.1 – B. Using either the amplitude (peak or average height of a specific ERP component) or the latency ERPs becomes comparable across experimental conditions or groups.

2.1.2 Advantages and disadvantages of using ERPs

Firstly, and most importantly, ERPs are a non-invasive means of measuring brain activity. The use of a high-density sensor net, containing up to 256 electrodes, allows for not only quick and easy application to the head but also clear and precise recording. Secondly, compared to behavioural measures, ERPs provide detailed information from the start of a cognitive process to the end, making it possible to track changes over time across experimental conditions with a high level of temporal resolution. Compared to other neuroimaging techniques, EEG provides extremely high temporal resolution, in the 1- 4 millisecond range making it possible to characterise brain responses that unfold very rapidly. ERPs are also less susceptible to participant manipulation than many experimental tasks or questionnaires and furthermore can often provide valuable information when there is no evident change in a behavioural response.

The disadvantages of using the ERP technique lie firstly in the sheer quantity of data needed to produce a clear ERP. Hundreds of experimental trials may be required to measure ERPs accurately, resulting in lengthy assessments which may prove problematic depending on the population that is being tested. As such, the design of an ERP experiment has to carefully consider the feasibility of the question it wishes to answer in relation to the length of time required to do so through using the ERP technique (Luck, 2005). A second disadvantage of using ERP's is its spatial resolution. Unlike other neuroimaging techniques like fMRI, ERPs have poor spatial resolution, making it difficult to localize the source of the signal (i.e. where in the brain the signal is coming from). In particular, what is recorded from electrodes placed at the scalp is a reflection of the summation of many source contributors reflecting various different cognitive processes (Luck, 2005). Although source-localization techniques have improved considerably over the years and we are much closer to identifying where the source is coming from, there are nevertheless significant challenges in localising EEG signals.

2.1.3 ERPs and Infants

The non-invasive method of recording brain activity using the ERP technique makes it the ideal system to use with human infants. Unlike other neuroimaging techniques that may pose risks (such as positron emission tomography), or be impractical (fMRI), EEG recordings are a safe and effective way of studying the neural bases of infant behaviour. The fact that ERPs do not rely on behavioural responses makes its use with infants, who have limited vocal and motor behavioural responses, even more attractive. Furthermore, recordings of ERPs are achievable from birth through to adulthood making it possible to draw useful parallels across the lifespan using the same methodology and experimental design (De Haan, 2013). However, recording ERPs in infants is not without its challenges. Infants' behavioural and emotional states are labile and this often impacts on both the preparation for the assessment and the actual recording of EEG. Short attention spans limit the length of the testing while large amounts of artefact in the EEG caused by muscle-related electrical interference (through movement) may introduce large amounts of noise to the analysis and may render some recordings unuseable. Another challenge is that infant EEG recordings may be more difficult to interpret than adult EEG recordings. This is partly because the infant brain is developing rapidly, with major changes occurring in synaptic density and myelination as well as physical changes to the density of the skull and the closing of the fontanel in the early years of life (DeBoer, Scott, & Nelson, 2007). Such changes ultimately influence the morphology of infant ERPs making it difficult, although not impossible, to draw parallels with adult neural responses.

2.2 Infant Emotional Face processing ERPs

This thesis aims to assess the association between indices of the early parent-infant relationship and infants' neural responses to emotional faces. In particular, this thesis will concentrate on the infant ERP components that have been empirically related to emotion and face processing. Below is a brief summary of these ERP components.

2.2.1 Early ERP component: The N290

The infant N290 ERP component is a negatively oriented deflection occurring between 250 and 350ms after stimulus presentation and is most prominent over posterior electrodes. The infant N290 ERP component is considered to be 'face-sensitive'. The N290 appears early in development and decreases in latency from 350ms to 190ms between the ages of 3 and 12 months (De Haan, 2007; Halit, De Haan, & Johnson, 2003). The N290 is considered to be a developmental progenitor to the adult N170, a well established adult ERP component linked to face processing (De Haan, Johnson, & Halit, 2003). The decline in latency of the N290 over the first year of life as well as similar response properties and topography to the adult N170 all provide support for this view. It has been suggested that an adult –like N170 finally emerges at around the age of four years old, reliably discriminating between faces and objects (Taylor, Edmonds, McCarthy, & Allison, 2001; Taylor, McCarthy, Saliba, & Degiovanni, 1999).

The N290 and N170 ERP components are both considered to be 'face-sensitive'. The adult N170 has consistently been shown to evoke faster and large amplitudes to human faces compared to all other stimuli (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Itier & Taylor, 2004; Rossion et al., 1999; Taylor, et al., 1999). While other non-face stimuli do evoke N170 responses, they are comparably smaller than the face effect (Rossion & Jacques, 2008). The N170 does not appear to distinguish between familiar faces and non-familiar faces (Bentin & Deouell, 2000; Eimer, 2000; Rossion, et al., 1999; Schweinberger, Pickering, Burton, & Kaufmann, 2002), leading to suggestions that the discrimination of facial identity takes place at a later stage of processing (Bentin & Deouell, 2000; Eimer, 2000; Zion-Golumbic & Bentin, 2007). As such, it is thought that the role of N170 reflects cognitive processes related to the structural encoding of the physical information contained in the face, as a direct result of activity in specialized occipital temporal brain areas (Allison, Puce, & McCarthy, 2000; Bentin, et al., 1996). This conclusion has been drawn particularly on the basis of evidence that has shown how experimental manipulation of the configuration of a face can lead to modulations of the N170 latency and amplitude. For example, the N170 exhibits larger amplitudes to inverted faces than to upright faces (Bentin, et al., 1996; De Haan, Pascalis, & Johnson, 2002; Eimer, 2000; Itier & Taylor, 2002, 2004; Rossion, et al., 1999) but does not differentiate between inverted and upright exemplars of non-face stimuli (Bentin, et al., 1996; Itier, Latinus, & Taylor, 2006; Rebai, Poiroux, Bernard, & Lalonde, 2001). Thus, it is widely assumed that the adult N170 is specific to face processing and has been identified, through source analysis, as stemming from activity in face-sensitive regions such as the fusiform gyrus and superior temporal sulcus (Itier & Taylor, 2004; Latinus & Taylor, 2006).

The infant ‘face-sensitive’ N290 ERP component draws its parallels with the adult ‘face-sensitive’ N170 ERP component through studies that employ the same stimuli and methodology and apply it to both infant and adult groups. In particular, early work by de Haan et al. (2002) highlighted a component that we now know as the infant N290, to be similar to the adult N170 in that it shared similar properties (i.e polarity and similar latencies) to the adult N170 as well as displaying a similar ‘face-sensitive’ pattern of larger amplitudes for human faces relative to monkey faces. This was further supported by Halit and colleagues (2003) who demonstrated that 12 month old infants displayed larger amplitudes in N290 for inverted human faces compared to monkey faces and showed similar effects in the adult N170. Although this inversion effect was not apparent at 3 months of age (Halit, et al., 2003), at this age infants' N290 responses to faces compared to noise matched those of the adult N170 in terms of amplitude and topography (Halit, Csibra, Volein, & Johnson, 2004). Unlike the adult N170, the N290 has also recently been shown to be sensitive to face familiarity (Righi, Westerlund, Congdon, Troller-Renfree, & Nelson, 2014; Scott, Shannon, & Nelson, 2006).

The emotional significance of the face has also been known to lead to variations in the amplitude of the adult N170 ERP component. It has been observed that emotional faces can elicit larger amplitudes on the N170 ERP component compared with neutral faces (Batty & Taylor, 2003; Blau, Maurer, Tottenham, & McCandliss, 2007; Righart & de Gelder, 2008; Rossignol, Philippot, Douilliez, Crommelinck, & Campanella, 2005; Willis, Palermo, Burke, Atkinson, & McArthur, 2010). In particular, fearful and angry facial expressions lead to enhanced amplitudes of the N170 compared to pleasant and neutral faces (Caharel, Courtay, Bernard, Lalonde, & Rebaï, 2005; Righart & de Gelder, 2006, 2008; Williams, Palmer, Liddell, Song, & Gordon, 2006). However, not all studies have shown an emotion effect on the adult N170 (Eimer & Holmes, 2007; Eimer, Holmes, & McGlone, 2003; Holmes, Winston, & Eimer, 2005).

Recent evidence has found that not only does the infant N290 share similar face processing functionality with the adult N170 but also is sensitive to emotionally relevant stimuli. To date only two studies have found an effect on emotion, but these, however, are contradictory. Specifically, Kobiella et al. (2008) reported modulation of the N290 face component, with greater amplitudes elicited for angry faces than for fearful faces. In contrast, Hoehl & Striano (2008) found that fearful faces elicited larger amplitudes at the N290 than to angry faces. This discrepancy in findings could possibly be explained by differences in recording sites. Kobiella et al. (2008) focused more on lateral sites while Hoehl et al. (2008) found an effect of emotion over central occipital channels.

2.2.2 Late ERP components: The P400

The infant P400 ERP component is a positive deflecting component occurring between 350 ms to 450 ms over posterior electrodes after stimulus presentation. Like the infant N290, the infant P400 has parallels with the adult 'face-sensitive' N170. The infant P400 is similar in topography to the N170, although the P400 is more apparent over lateral than medial site (De Haan, et al., 2002; Halit, et al., 2003) but displays similar 'face-sensitive' modulations (De Haan, 2013; Halit, et al., 2003). In particular, the P400 peaks faster for face stimuli than for non-face stimuli (De Haan & Nelson, 1999) and in early development the P400 is able to distinguish between inverted and upright faces (Halit, et al., 2003). Similar to the N290, the P400 early on in development is not specific to human faces but becomes increasingly so during the course of the first year. In particular, by 12 months of age the infant P400 latency is longer for inverted human faces than inverted monkey faces, a response similar to that of the adult face-sensitive N170 component (Halit, et al., 2003). The infant P400 has recently been shown to be sensitive to face familiarity with Swingler et al. (2010) showing increased P400 amplitudes to mothers faces vs strangers faces and as a result of this it has been suggested that the P400 may play a part in visual attention and memory as opposed to just face processing.

The infant P400 has also been shown to be modulated by emotionally salient stimuli. In particular, negative emotions elicit greater responses in terms of amplitude on the P400 (Hoehl, et al., 2008; Kobiella, et al., 2008; Leppänen, et al., 2007).

Notably, there are clear differences between the adult N170 and infant P400, namely their polarity and latency, which could be taken to undermine the argument that the P400 is a precursor of the adult N170. However, it is argued that it is difficult to make direct comparisons based on topographic distribution and timing due to the prominent neurological and physical changes that occur early on in development. Rather, comparisons should be sought in relation to the functional processes that might be reflected in individual ERP components (De Haan, et al., 2003), as represented by the ‘face-sensitive’ functionality between the adult N170 and the infant P400.

2.2.3 Late ERP Components: The Negative Central (Nc)

The Nc has been shown to be present after birth and is considered to be the first ERP to emerge in development (Kurtzberg & Vaughan Jr, 1986). During development the infant Nc ERP component has been consistently associated with face processing (for a review see De Haan, et al., 2003). The infant Nc is a negative deflecting component occurring mostly over frontal and central sites. Its latency decreases over the course of development but the amplitude of the Nc appears to increase over the first year (Richards, 2003) and then begins to decrease around three years of age (Parker & Nelson, 2005). The developmental trajectory of the Nc seems to be complete by the age of 7 years (Courchesne, 1978) with the Nc disappearing sometime during early adolescence (Courchesne, 1978; Courchesne, Ganz, & Norcia, 1981). As well as face-sensitive properties of the Nc, the Nc also appears to be sensitive to stimulus probability and familiarity, eliciting larger (i.e. more negativity) amplitudes to familiar and/or infrequent events (for a review see De Haan, 2007; De Haan, et al., 2003; De Haan & Nelson, 1997; Karrer & Ackles, 1987).

In regards to face processing, the infant Nc has been found to discriminate between familiar and non-familiar faces in infants. In particular, it is infants' responses to their own mother versus a stranger's face that have highlighted such modulations. It appears that a larger Nc (greater negativity) is evoked in response to a mother's face relative to a stranger's face in children under the age of 24 months (Carver et al., 2003). In particular, at 6 months of age infants display a larger Nc (i.e more negativity) to both their mothers face and a familiar object in comparison to a stranger's face and unfamiliar object (De Haan & Nelson, 1997, 1999). However, children over the age of 45 months show the opposite response, with stranger's faces eliciting a larger response (i.e more negativity) than mother's faces (Carver, et al., 2003). Interpretation of such findings allude to the saliency of the mothers face in the first year of an infant's life and the possible role of the infant Nc in recognition memory (Courchesne, et al., 1981; Nelson, 1997). Carver (2003) suggest that in the early years of an infant's life the mother has a prominent role in the infant's survival and as such her face becomes increasingly important to the infant and secures its place in memory. However, as the infant develops, attention shifts to the outside social world to promote individual identity as possibly indexed by the change in Nc activity.

This apparent sensitivity to the familiarity of stimulus presented for the infant Nc, has led researchers to draw parallels with the adult N400 ERP component. The infant Nc exhibits similar topography and latency to the adult N400 as well as possible similarities in functionality in relation to face familiarity (Bentin & Deouell, 2000; Eimer, 2000).

In infancy, the Nc has consistently been shown to be sensitive to emotional stimuli. In particular, it is firmly established that by 7 months of age the Nc elicits greater (more negative) amplitudes to negative emotion. Larger amplitudes on the Nc to fearful faces have been robustly demonstrated (De Haan, et al., 2004; Leppänen, et al., 2007; Nelson & De Haan, 1996; Peltola, et al., 2009). These ERP findings are further supported by behavioural data in which infants at 7 months sustain attention longer (Kotsoni, et al., 2001) and are slower to disengage from a negative face (Peltola, et al., 2011). This evidence suggests that by the age of 7 months, infants may be becoming increasingly attuned to social signals of threat (angry and fearful faces). However, interestingly this effect of negative emotion is not seen at 5 months of age (Peltola, et al., 2009).

It is widely assumed and accepted that modulation of the Nc's amplitude is a reflection of an infant's allocation of attention. In particular, the emergence of the Nc is thought to reflect an automatic orienting of attention (Richards, 2003; Vaughan Jr & Kurtzberg, 1992) whereas the modulation of the Nc's amplitude is thought to be related more to controlled and sustained attention (Ackles & Cook, 1998). It is clear that the saliency of the stimuli presented to the infant is particularly relevant to the Nc, as seen in both the emotion related findings and face familiarity results. Early detection and thus allocation of attention to negative emotion is likely to be evolutionarily adaptive. Negative emotions may arouse greater vigilance in the infant requiring them to allocate more attention (Nelson, 1993). Likewise, the relevance that a caregiver's face holds to an infant for their survival is of equal importance. As such, it is argued that Nc activity is a reflection of the saliency of the stimulus presented and the corresponding allocation of attention, whether the stimulus is familiar or not (Reynolds & Richards, 2005).

2.3 Experimental Paradigm and ERP Processing

This thesis employed a ‘passive viewing’ paradigm. This paradigm is particularly useful when working with infants as it requires no instructions or behavioural responses. A selection of faces depicting emotional expressions was chosen from the MacBrain Face Stimulus Set. Development of the MacBrain Face Stimulus Set was overseen by Nim Tottenham and supported by the John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development. A total of five female actors each posing a happy, neutral or fearful face were selected (see figure 2-2). The total number of trials that an infant was exposed to was up to 210 emotional faces in a single experimental block (70 neutral, 70 happy and 70 fearful). The faces were posed against a white background and were cropped so that limited hair or other peripheral features could be seen. The static images were centrally positioned and measured 12cm X 9cm on a 10.5 inches X 13.5 inch screen with a viewing distant of 50 cm. Each trial was shown for a duration of 500 milliseconds and was randomly presented. The inter-stimulus interval (ISI) was random between 500 and 1000ms.

Figure 2-2 Emotion Face Stimuli

Development of the MacBrain Face Stimulus Set was overseen by Nim Tottenham and supported by the John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development.

2.3.1 EEG Data Acquisition

EEG data were collected using the Electrical Geodesic system (Electrical Geodesics Inc. (EGI), Eugene Oregon, USA). 129-channel high-density hydrocel geodesic sensor nets (HGSN) was soaked in a prepared saline solution of potassium chloride and shampoo. This solution is used to improve the transmission of electrical signal between the scalp and the electrical sensors. While infants' sat on their parents lap a trained researcher applied the electrode cap in accordance to EGI guidelines. Distraction by the use of toys and bubbles was employed to ensure that fussiness was kept to a minimum and that the sensor net was placed correctly and in the same position for each infant. Although correct placement of electrode nets is always a challenge with young infants it is vital to ensure comparability across data sets. EEG data was recorded continuously throughout the emotional face viewing paradigm. If infants looked away from the screen or became fussy an 'attention getter' was deployed which involved a flashing animation of shapes with accompanying sound of a bell to draw the infants attention back to the screen. This is a standard approach used in infant neurocognitive research. Sessions were termed completed once the infant had completed the block or until they became too fussy to continue with the experiment.

Figure 2-3 Infant wearing a 129-channel high-density hydrocel geodesic sensor nets

2.3.2 *EEG Pre-processing*

During the acquisition of continuous EEG data the analogue signal was amplified with a 0.1-to 100-Hz signal at a sampling rate of 250Hz. The collected EEG data was analysed offline using custom made MATLAB scripts. For each participant the EEG signal was segmented into an epoch ranging from 100ms before stimulus onset (the emotional face) and extending to 750ms after stimulus onset. Before any EEG data was analysed, the video recording of the infant was examined thoroughly and segments were rejected where the infant appeared not to be looking at the screen. The remaining data that the participant attended to was then digitally filtered to suppress noise in a chosen band-pass range of 0.1Hz to 30Hz. Data was then baseline corrected to an interval that began at the start of the epoch and lasted 100ms. This standard baseline was selected as it is assumed that this period of data is unaffected by the stimulus. Before any further analysis was carried out this filtered, baseline corrected and segmented data was inspected for artefacts. Artefacts are unwanted noise that presents itself in the data in the form of high-amplitude or off scale activity as well as high frequency noise. The main sources of artefacts in infants arise from extreme body movement as well as electromyogram (EMG muscle movement) and electrooculogram (EOG eye movement) activity (DeBoer, et al., 2007). Although there are standard artefacts algorithms that are used with adult ERP data, a standard practice in infant ERP research is to inspect individual segments by eye and remove trials manually based on artefact detection. This is to ensure that there is not unnecessary data loss due to pre-set thresholds. During artefact detection, noisy and bad electrode channels were identified and interpolated. Electrode interpolation is designed to estimate the identified electrode's channel data by drawing on the data of the surrounding electrodes, a method known as spherical spline interpolation. All data is then re-referenced to the average reference. When recording an electrical potential one assumes that it is being recorded in respect to a reference, as you are technically measuring a voltage difference between two points (i.e. the electrode and a reference point). The reference point that is selected depends on the recording system employed in a study. In systems where there are more than 64 channels, as in the system employed in this thesis, it is suggested that an 'average reference' is selected as opposed to a single point on the head i.e the earlobe as a reference point (Luck, 2005).

During ‘average referencing’ the average of all electrodes is subtracted from each individual electrode.

Re-referenced data were collated and averaged to produce individual single subject averages. Averaging is required to reduce the within-subject variability of the ERP waveform and the signal-to-noise ratio. As such, the data that contributed to this thesis had the criteria applied that there needed to be at least ten trials per experimental face viewing condition (fearful, happy and neutral) for each individual subject average. Without this criterion the signal-to-noise ratio would have been compromised.

Finally, data relating to the amplitude of interested ERP components was extracted from single subject ERP waveform averages. The location on the head for each infant ERP component of interest was selected by following past reports as well as being guided by the grand average containing all data ERP sets, and an inspection of the single subject averages. As a result, three ERP face-sensitive components were selected for analysis, the Negative Central (Nc), the N290 and the P400. The Nc is reported to be most prominent over frontal and central sites (De Haan, et al., 2004; De Haan, et al., 2003). Inspection of the grand average displayed a more prominent Nc over central electrodes, so in order to avoid unnecessary statistical analysis the following central electrode clusters were selected for each hemisphere; left: 35, 41, 36, 47, 42 and right: 110, 104, 103, 93, 98. See figure 2.5 for topographic distribution of the Nc. The time period selected for the Nc began at 350ms after stimulus presentation and extended to 650ms. The N290 and P400 are most prominent over posterior lateral sites (De Haan, 2007; Leppänen, et al., 2007) and as such the same electrode cluster for both components was selected; left: 66, 70, 65, 69, 64 and right: 84, 83, 90, 95, 89. The N290 was examined in the time window of 250ms post stimulus and extended to

350ms. For the P400 the time period selected was 350ms after stimulus onset and extended to 600ms. See figure 2.5 for electrode selection.

Figure 2-4 Nc Topographic Distribution

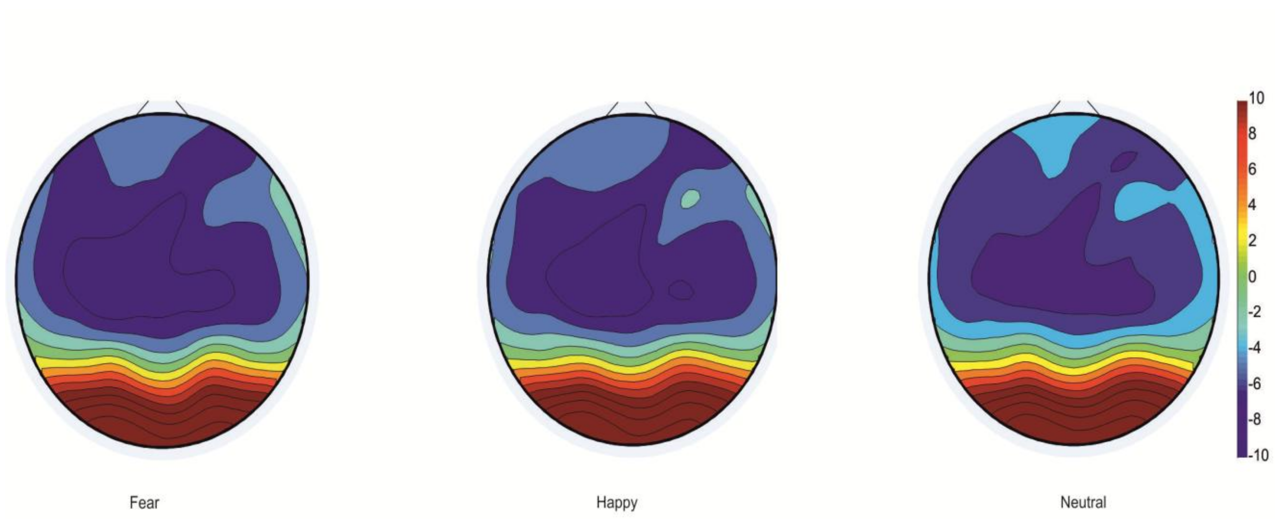
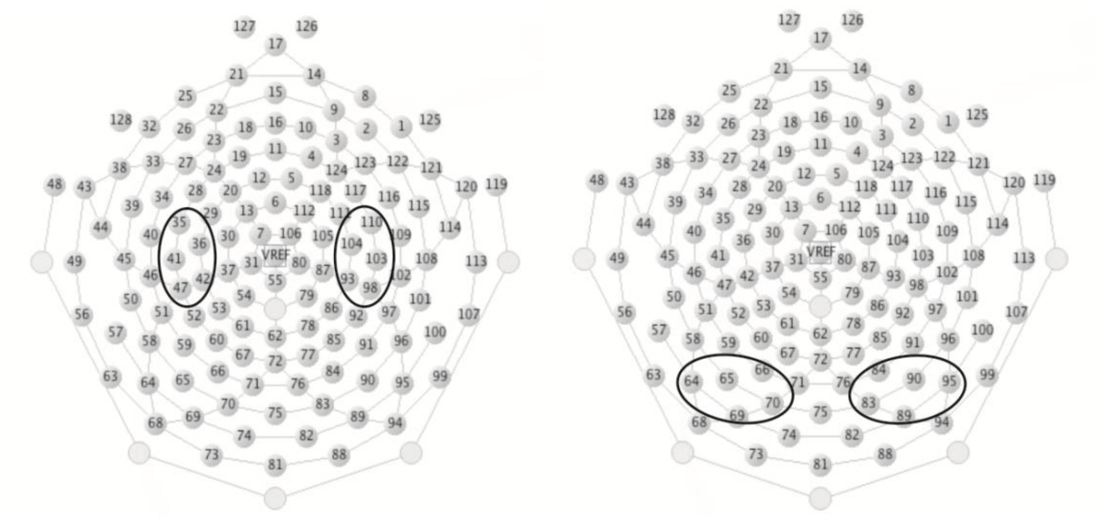


Figure 2-5 Selected Channel Clusters



Negative Central (Nc)

N290 & P400

2.3.3 Thesis Sample:

The sample for this thesis was drawn from a large database of parents from the community who agreed to be contacted regarding developmental studies. These parents were initially recruited through researchers visiting local groups that parents and their children would be attending, such as playgroups, libraries, baby massage groups, baby clinics and breastfeeding support groups. Researchers would approach and talk to parents, explaining the various developmental projects being carried out at the Developmental Neuroscience Lab. Parents were also able to register for participation through leaflets and posters that were left across various places that parents would visit. Interested parents would pass on contact details to be contacted at a later date to see if they would be interested in taking part in a study. Participation was completely voluntary.

For each study the exact details of participation are explained in more detail in the corresponding chapter however, an overview is provided here. Overall 130 parents and their 7 month old infants took part in this research. Out of 130, 71 infants had usable EEG data. This attrition rate is consistent with other infant ERP studies and is not considered a threat to the validity of this research (De Haan, et al., 2004; Leppänen, et al., 2007). Out of the 71 usable infants, 5 parents did not complete the questionnaire assessing infant temperament, leaving a total sample of 66 for chapter 3. In regards to maternal mental health (chapter 4) the total participant numbers are as follows; for the depression scale 69, for maternal anxiety 68 and 65 for levels of parental stress. Out of the 130 infants, 77 had recordings of parental sensitivity, out of these 77, 40 had useable EEG data for assessing the effects of parental sensitivity on infants ERP responses to emotion in chapter 5. And finally, again out of the 71 usable infants 68 had codable strange situation data for chapter 6.

2.3.4 Statistical Analyses and Assumption of Normality

Given the large sample size, it is assumed that the sample distribution is normal and as such justifies the use of parametric analysis. However, to ensure that the sample under test was from a population with normal distribution Shapiro-Wilk tests and inspection of Q-Q plots and/or histograms were carried out. Overall, parametric analyses were justified.

3 The Role of Temperament in Infants’ Neural Processing of Emotion

Temperament is considered to be a largely genetically influenced set of early-appearing behavioural and affective traits, although it is also considered to be shaped through individual experience across development (Bates & Pettit, 2007). The nature of a child's temperament is thought to predispose them towards trajectories that impacts on both their future emotional and social development (Sanson, Hemphill, Yagmurlu, & McClowry, 2011). An abundance of research has highlighted the predictive association between temperament and emotional and social functioning (see Rothbart, Bates, Damon, & Lerner, 2006), but only a handful have assessed the underlying neural mechanisms linked to different temperament traits. Although the focus of this thesis is the examination of the environment's effect, stemming from the parent-infant relationship, on infants' neural processing of emotion, it is relevant and important to also consider whether individual differences in genetically inherited temperamental traits may be related to altered neural response to emotional stimuli. Specifically, this chapter will investigate the relationship between parent-reported assessments of infant temperament and infants' ERP responses to emotional faces. By assessing individual temperamental dimensions in relation to neural response to emotion, this investigation can shed light on the underlying neural mechanisms relevant to emotional development.

3.1 Introduction

3.1.1 Defining Temperament

Temperament can be defined as 'early emerging basic dispositions in the domains of activity, affectivity, attention and self-regulation, and these dispositions are the product of complex interactions among genetic, biological, and environmental factors across time" (Shiner et al., 2012 p.437). Thomas, Chess and colleagues (1963) were the first researchers to identify and categorise children's different behavioural styles into temperamental dimensions. The original nine scales consisted of approach-withdrawal, adaptability, quality of mood, intensity of reaction, distractibility, persistence or attention span, rhythmicity (regularity of eating, sleeping and toileting), threshold of responsiveness and activity level. Based on these individual dimensions, Thomas and Chess (1963) developed an 'easy-versus-difficult' categorisation system. For example, 'difficult' children display a temperamental profile of increased negative mood, more withdrawal, less adaptability, are highly intense and often arrhythmic. Despite this important advance, low internal consistency and conceptual overlap between dimensions led modern researchers to redefine these categories. As a result, three broader dimensions have emerged within the realm of modern temperament research, *negative emotionality (reactivity), extraversion/surgency* and *effortful control (self regulation)* (Rothbart, et al., 2006). *Negative Emotionality* or *Reactivity* is considered to reflect how easy it is to arouse emotions, attention and motor responses. High intense negative responses and/or distress to limitations (anger or irritability) or novelty (fearfulness) is a defining feature. Reactive temperament is measurable in terms of the latency and duration of the response to the situation as well as the intensity of the response and how quick recovery is. *Extraversion/Surgency* is thought to relate specifically to positive emotionality, with activity level, impulsivity and risk taking behaviours being key components. *Effortful Control (self-regulation*) refers to how an individual regulates behaviour and emotion through attention to either increase or decrease the onset, intensity and duration of a particular reaction (Rothbart, et al., 2006; Rothbart & Derryberry, 1981).

Unlike adult personality traits, infant temperament is considered to be only moderately stable over time (Slabach, Morrow, & Wachs, 1991). Although temperamental changes in the early years are not clearly understood, it has been suggested that it occurs through a combination of brain maturation and environmental input (Rothbart, Sheese, Rueda, & Posner, 2011). This notion is highlighted by the evidence that suggests that aspects of effortful control, thought relevant in self-regulatory traits, depends on the maturation of the frontal lobes late in the first year of life (Rothbart, Derryberry, & Posner, 1994; Rueda, Posner, & Rothbart, 2004). In addition, the role that parenting may have in influencing temperamental traits has become increasingly apparent (Hinde & Stevenson-Hinde, 1987; Putnam, Sanson, & Rothbart, 2002; Rubin, Cheah, & Fox, 2001; Sanson, et al., 2011; van den Boom & Hoeksma, 1994) . Interestingly, temperament appears to become more stable with age, with the preschool years showing increasing stability in temperamental traits (Roberts & DelVecchio, 2000). This increase in stability across the early years draws attention to the malleable aspect of temperament in infancy and its vulnerability to environmental input.

3.1.2 Temperament and Emotional and Social Development

An individual's temperamental disposition and its relationship to later emotional and social development have been extensively researched. A great deal of research has focused on the effects of *Negative Emotionality and/or Reactivity* on emotional development. In particular, certain aspects of *negative emotionality*, i.e. irritability, impulsivity and anger have led some researchers to argue a direct link to later aggressive and antisocial behaviours (Cairns & Cairns, 1991; Ledingham, 1991; Rothbart, et al., 1994). Furthermore, distinct behaviours within the *negative emotionality* structure such as, impulsivity, distractibility and high intense affect have been suggested to be significant predictors of externalising behaviour problems later in life (Eisenberg, Fabes, Guthrie, & Reiser, 2000; Hagekull & Bohlin, 1994; Maziade et al., 1990). Socially, children categorized as having high levels of *negative emotionality* tend to have poorer social skills (Eisenberg et al., 1993) as well as less sympathy when interacting with peers (Murphy, Shepard, Eisenberg, Fabes, & Guthrie, 1999). *Reactivity*, has been empirically identified to predict later inhibition and internalising behavioural problems (Kagan, Snidman, Zentner, & Peterson, 1999) with persistent r*eactivity*, assessed over multiple time points, accounting for 42% of later anxiety problems in adolescence (M. Prior, Smart, Sanson, & Oberklaid, 2000).

Self –regulatory temperamental traits, including high levels of emotion regulation, have been predictive of increased social competency (Fabes et al., 1999; Paterson & Sanson, 1999; Yagmurlu & Sanson, 2009) including higher levels of teacher and parent reported sympathy (Eisenberg, et al., 1993). Interestingly, poorly regulated children appear to be generally at risk for later emotional behavioural problems, as low regulatory traits have been associated with both internalising and externalising behavioural problems (Eisenberg, Cumberland, et al., 2001; Eisenberg et al., 2000; Eisenberg et al., 2009; Kochanska & Knaack, 2003; Olson, Sameroff, Kerr, Lopez, & Wellman, 2005; Rydell, Berlin, & Bohlin, 2003; Zeman, Shipman, & Suveg, 2002) . In particular, it appears that individuals who are low on self regulatory behaviours but are highly sociable tended to have more externalising behavioural problems whilst those with low sociable traits and low self-regulatory behaviours tended to display more internalising behavioural problems (Rubin, Coplan, Fox, & Calkins, 1995).

It is clear that a core component of these behavioural differences is a heightened emotional response. Thus, in considering the underlying neural bases of temperament, it is logical to focus on brain systems involved in emotion.

3.1.3 Neural Bases of Temperament and Emotion Processing

Recent research from a neuroscientific perspective has focused on the relationship between infant temperament and neurological activity. In particular, a great deal of research has focused on infant frontal EEG asymmetry and its hemispheric distribution as potentially underpinning specific temperamental traits. It is now widely accepted that greater right hemispheric prefrontal activity is associated with withdrawal-related activity, whilst left hemispheric prefrontal activity is associated with approach-related activity. This is not only evident in infancy (Calkins, Fox, & Marshall, 1996) but also in adulthood (Davidson, 1992). Both withdrawal and approach tendencies have been suggested to reflect distinct exploratory and inhibitory dispositions related to temperament and personality dimensions (Corr, DeYoung, & McNaughton, 2013; Davidson & Fox, 1989; Elliot & Thrash, 2002). Specifically, greater right frontal asymmetry in infancy has been seen to relate to behavioural inhibition (Fox, 1991), social withdrawal (Fox et al., 1995), social wariness (Henderson, Fox, & Rubin, 2001) and fearful/shy temperamental traits (Calkins, et al., 1996; Davidson & Rickman, 1999; Finman, Davidson, Colton, Straus, & Kagan, 1989; Fox, et al., 1995) while greater left activation was associated with greater social competence (Fox, et al., 1995) . In addition to resting EEG activity, fontal asymmetry *response* to emotional stimui is also thought to reflect the activity of these approach-withdrawal systems. Specifically, greater left activation in prefrontal areas was displayed when infants viewed positive emotional faces compared to negative emotional faces (Davidson & Fox, 1982) .

Interestingly, despite a clear interaction between temperament, neural activity, and emotion there are few studies that have directly assessed these possible associations together. This is surprising given the crucial role that emotion plays in temperamental traits.

Two neuroimaging studies to date have examined a direct relationship between infant temperament and the neural processing of emotion. Firstly, De Haan and colleagues in (2004) assessed the effects of temperamental dimensions, as measured by parent self-report, on infant's ERP responses to positive and negative emotional faces. They concluded that infants who were rated as highly fearful by parents had increased neural activity at the frontal ERP component the Nc to images of fearful faces, particularly over the right hemisphere. This hemispheric distinction is clearly consistent with the data from frontal asymmetry studies, including data specifically relating fearful temperament to right asymmetry activation (i.e., Calkins, et al., 1996) as well as the evidence relating the processing of negative emotion and right hemisphere activation (Davidson, 1992). A more recent study by Martinos and colleagues (2012) employing the same ERP methodology and a parent-report temperament measure, found that infants who were rated as having increased negative emotionality had larger neural activity to positive emotion over the right hemisphere for the ERP component the Nc. In addition, infants who were rated as having high self-regulatory traits had larger neural amplitudes to fearful faces over the right hemisphere on the Nc component. The authors argue that given the role that attention plays in eliciting greater neural responses on the Nc component, it is possible to assume that those infants with high levels of self-regulatory behaviours are allocating more attention to fearful faces in order to faster regulate their response to threat based stimuli. The intriguing finding in this study is that infants scoring high for negative emotionality had increased neural responses to positive emotion over the right hemisphere, contradicting the results reported by De Haan et al. (2004). Methodological reasons, including age discrepancies between the two studies (De Haan focused on infants 7 months of age whereas Martinos et al. focussed on infants 3 to 13 months of age) may play a part in the apparently contradictory results.

The neuroscientific research mentioned above is clearly in need of replication to narrow down the impact that temperament plays in neural response to emotion. As such, this investigation will employ similar ERP methodology to the studies of De Haan and Martinos, using facial displays of emotion to elicit neural response in relation to parent-reported measures of temperament. Specifically, it will look at infant’s ERP responses to happy, fearful and neutral facial expressions at three empirically identified ERP components thought relevant in facial emotion processing, the Nc, the P400 and the N290. By using highly salient emotional stimuli - emotional faces - we should be able to directly tap into the current ongoing neurological changes that are occurring during emotion processing. These ERP responses will be assessed in relation to parents' responses to the well validated and most widely used measure of temperament; the Infant Behaviour Questionnaire (IBQ). The IBQ scores produce 6 temperamental dimensions but given the theoretical understanding relating specifically to the importance of negative emotionality and self-regulation in regards to emotional development, this study will specifically focus on these two dimensions. This will not only provide a more reliable measure of temperament but will also reduce the number of variables for analysis. Given the contradictory findings relating to De Haan and Martinos, directional hypotheses are not proposed. Not only does the investigation aim to provide further evidence concerning the neural systems involved in emotion processing in infancy but also that activity in these emotion-related neural systems can be associated with individual temperamental traits.

3.2 Methods

3.2.1 Participants

The sample for this study was drawn from a large database of parents from the community who agreed to be contacted regarding developmental studies. For a full description please see chapter 2. In this investigation, 130 seven month old infants (mean age 223 days, 69 males and 61 females) and their mothers out of the community sample database were invited in to participate. The final sample consisted of 66 healthy mothers and their 7 months old infants (mean age in days 230, males 33 and 33 females). Fifty-nine infants were excluded due to fussiness/inattentiveness and excessive ERP artefact including eye and body movement. This attrition rate is consistent with other infant ERP studies (De Haan, et al., 2004; Leppänen, et al., 2007). A further 5 infants were removed due to parents failing to complete the temperament questionnaire. All infants were born full term (i.e., 37-42 weeks) and of normal birth weight (>6 lbs, 2 oz).

3.2.2 Measures

Infant Behaviour Questionnaire (IBQ Rothbart, 1978)

The IBQ assesses the frequency of specific temperamental behaviours that have been observed in the last week and is intended for infants aged between 3 and 12 months. Parents completed the 94 item self-report measure using a 7-point scale (never to always) prior to their visit at the lab. The IBQ results in six temperamental dimensions, activity level, smiling and laughing, distress and latency to approach sudden or novel stimuli, distress to limitations, soothability and duration of orienting. This study will focus on the theoretical and empirical dimensions deemed highly relevant in emotional development; negative emotionality/reactivity and self-regulation. For negative emotionality/reactivity the two distress dimensions, *distress and latency to approach sudden or novel stimuli and distress to limitations*, were correlated (r =.34) and as such, a composite score was created by computing *z* scores and summing the dimensions to produce a negative emotionality scale. The soothability dimension will provide evidence for self-regulatory traits. High internal reliability across all 6 dimensions has been demonstrated at 3, 6, 9 and 12 months of age (Rothbart, 1981). The IBQ was completed at home before mothers and infants visited the lab. They were instructed to contact the researcher if any questions were unclear or if they needed any further help. Please see table 3.1 for the IBQ sample distribution.

Table 3-1 Sample Distribution

IBQ Sample Distribution N = 66	
Distress to Limitations	
Mean (SD)	3.22 (.67)
Range	1.7 – 4.7
Distress and Latency to Novel Stimuli	
Mean (SD)	2.21 (.60)
Range	1.0 – 4.31
Soothability	
Mean (SD)	4.31 (1.04)
Range	2.5 – 7

3.2.3 Emotional Stimuli:

As previously described in chapter 2, the stimuli consisted of 5 female actors each posing a happy, neutral or fearful face. A total of 210 face trials, 70 in each emotional face condition, were used. The faces were all posed against a white background and the images were cropped so that no hair or other features could be seen. The static images were centrally positioned and measured 12cm X 9cm on a 10.5 inches X 13.5 inches screen. The stimuli were provided by the MacBrain Face Stimulus Set. Development of the MacBrain Face Stimulus Set was overseen by Nim Tottenham and supported by the John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development.

3.2.4 Procedure:

Infants sat on their parent's lap in a soundproofed room at a viewing distant of 50cm from a 10.5 inches X 13.5 inches screen. The experiment consisted of one block of 210 trials (70 Happy, 70 Fearful and 70 neutral). Each trial was presented for a duration of 750 milliseconds and was randomly presented. The inter-stimulus interval was random between 500 and 1000ms. Trials began once infants' attention was drawn to the screen. The infants' behaviour was monitored by a researcher through a video camera in the next room. If the infant became fussy the researcher activated a bright colourful animation with sound to redirect infants' attention to the screen. When an infant's attention could no longer be redirected to the monitor the session was terminated. Parents were instructed to not interact with their infant at all during the session. Furthermore, they were instructed to avoid eye contact and look straight ahead if their infant turned to look at them. On average, the sessions lasted about 20 minutes including, EEG net application, recording of 3 minutes of resting data and participating in the face viewing paradigm.

3.2.5 EEG Recording:

EEG was recorded continuously through the face viewing trials using a 128 hydrocel geodesic net (Electrical Geodesic Inc. Eugene, OR) referenced to the vertex (Cz). The electrical signal was amplified with a 0.1-to 100-Hz band-pass with a sampling rate of 250Hz. All EEG data were analysed offline using the EEG platform EEGLAB (Delorme & Makeig, 2004) and in-house custom made MATLAB scripts.

3.2.6 Data Reduction:

For each infant participant the EEG signal was segmented into an epoch ranging from 100ms before stimulus onset and extending to 750ms after stimulus onset. Data were digitally filtered offline at a high-pass filter of 0.1Hz and a low-pass filter of 30Hz with bad channels being replaced using spherical spine interpolation. Visual inspection of the EEG segments was carried out to remove segments that had artefacts relating to eye and body movement or high frequency noise. Furthermore, the video recording of the infant was examined thoroughly and segments were rejected when the infant was not looking at the screen. Independents component analysis was run using FASTER to remove stereotyped artefacts (Nolan, Whelan, & Reilly, 2010).With a minimum of 10 trials per experimental condition data were averaged, re-referenced and baseline corrected. The average number of good trials was 21 for fearful, 22 for happy and 21 for neutral. This rate of data loss is consistent with other infant ERP studies (De Haan, et al., 2004; Leppänen, et al., 2007) and is not considered a threat to the validity of the experiment.

3.2.7 Statistical Analysis

Based on prior ERP studies of emotion processing, the following three infant ERP components were selected, the Negative Central (Nc), the P400 and the N290. Time windows for all three infant ERP components, the Nc, P400 and N290 were created by examining the grand average waveform for all participants and looking at past studies' selected time windows.

Negative Central (Nc): The Nc was selected at 350ms after stimulus onset and extended to 650ms after stimulus onset. The Nc has been reported to be most prominent over frontal as well as central sites (De Haan, et al., 2004). Inspection of the grand average for our data revealed an Nc more prominent over central electrodes. As such, to avoid unnecessary data analysis the following central electrode clusters were selected for each hemisphere; left: 35, 41, 36, 47, 42 and right: 110, 104, 103, 93, 98.

N290 and P400: The N290 and P400 are most prominent over posterior lateral sites and as such we used the same electrode cluster for both components; left: 66, 70, 65, 69, 64 and right: 84, 83, 90, 95, 89. The time window selected for the P400 was 350ms after stimulus onset and extended to 600ms after stimulus onset. The N290 began at 250ms after stimulus onset and ended at 350ms after stimulus onset. See figure 3-1 for channel cluster locations.

Figure 3-1 Selected Channel Clusters

Negative Central N290 & P400

Analysis of amplitudes for all components, N290, P400 and the Nc, involved the use of mixed 2 (hemisphere; left versus right) x 3 (Emotion; Fear, Happy, Neutral) ANOVAs, with IBQ subscales entered as a continuous covariate. Correlational analyses were employed to investigate any temperamental effects, based on a subtraction of the average ERP amplitudes (N290, P400 and Nc) for emotion faces from neutral faces (Fear minus Neutral and Happy minus Neutral). This contrast was selected because the main focus of this investigation is infants’ neural responding to emotion, and hence the neutral/nonemotional face stimuli represented the most relevant reference point.

3.3 Results

3.3.1 Emotion Effect on Infant Face Sensitive ERP Components

The Nc: The main effect of emotion on the Nc was statistically significant, indicating that mean Nc amplitudes differed according to the emotion of the face stimuli ($F_{2,130}$ = 6.887, p = .001, η_p^2=.096). Consistent with previous findings, fearful faces elicited larger amplitudes (M = -5.08) than Happy (M = -4.17) and neutral (M = -3.52) faces (see figure 3.2). There was no statistically significant effect of laterality on the Nc ($F_{1,65}$ = .024, p =.877, η_p^2=.000).

The N290: There was no statistically significant main effect of emotion on the N290, suggesting that the mean N290 amplitudes did not differ according to the type of emotion experienced ($F_{2,130}$ = .542, p =.583, η_p^2=.008). Neither was there a significant effect for laterality ($F_{1,65}$ = .076, p =.784, η_p^2=.001).

The P400: There was no statistically significant main effect of emotion on the P400, suggesting that the mean P400 amplitudes did not differ according to the type of emotion experienced ($F_{2,130}$ = 2.014, p =.138, η_p^2=.030). Neither was there a significant effect of laterality ($F_{1,65}$ = .044, p =.835, η_p^2=.001).

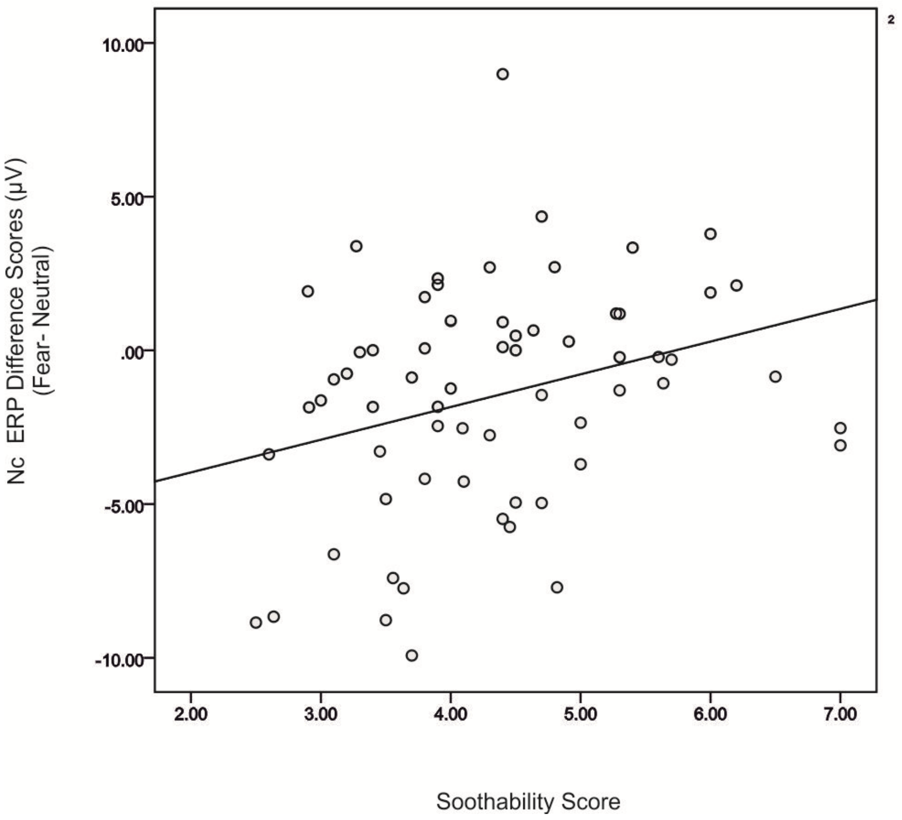
3.3.2 Effects of Infant Temperament on the Nc ERP Component

When *Soothability* was included as a continuous covariate there was a significant main effect of emotion ($F_{2,126}$ = 5.708, p =.004, η_p^2=.083). There was no significant effect of laterality ($F_{1,63}$ = .621, p =.434, η_p^2=.010). Amplitudes were larger for fearful faces compared to happy and neutral faces. In addition, there was a statistically significant emotion x *Soothability* interaction ($F_{2,128}$ = 3.419, p =.036, η_p^2=.051). To tease apart this interaction, two difference scores were created reflecting the amplitude of each emotional face relative to neutral faces (Fear - Neutral, Happy -

Neutral) and both were correlated to *Soothability* scores. Follow up correlations between *Soothability* and the Nc ERP difference scores found a significant correlation for the relative Nc amplitude for fearful faces (r = .29, p = .02), but not happy faces (r = .064, p = .612) relative to neutral faces. The direction of the correlation implies that infants with lower soothability ratings had a larger (more negative) Nc amplitude to fearful faces, relative to neutral faces. Notably, this correlation maintained even after controlling for infant gender (r =.29, p = 02).

When the composite score of *negative emotionality/reactivity* was entered there was a significant main effect of emotion ($F_{2,126}$ = 6.507, p =.002, η_p^2=.094). The main effect of laterality was not significant ($F_{1,63}$ = .049, p =.826, η_p^2=.001) and the interaction between emotion and negative emotionality and/or reactivity was not significant ($F_{2,126}$ = .230, p =.795, η_p^2=.004).

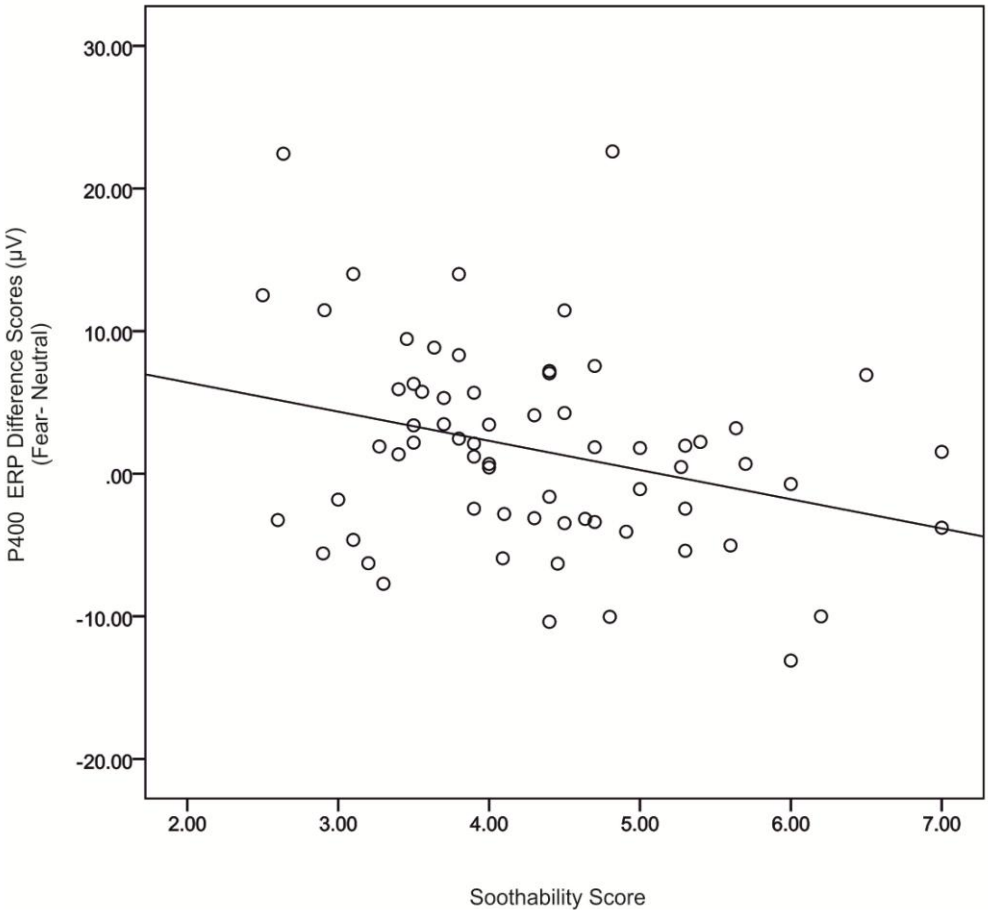
Figure 3-2 Scatterplot Nc and Soothability



3.3.3 Effects of Infant Temperament on the P400 ERP Component

There were no significant main effects or interactions for the composite score of *negative emotionality/reactivity*. When *Soothability* was included as a continuous covariate there was a statistically significant emotion effect ($F_{2,126}$ = 4.093, *p* =.019, η_p^2=.019) . There was no significant main effect for laterality ($F_{1,63}$ = .875, *p* =.353, η_p^2=.014). In addition, there was a statistically significant emotion x *Soothability* interaction ($F_{2,126}$ = 3.182, *p* =.045, η_p^2=.048). As mentioned previously, to tease apart this interaction, two difference scores were created (Fear - Neutral, Happy - Neutral) and both were correlated to *Soothability* scores. Follow up correlations between *Soothability* and the P400 ERP difference scores found a significant correlation for the relative P400 amplitude for fearful faces (*r* = -.263, *p* = .034), but not happy faces (*r* = .044, *p* = .727) relative to neutral faces. The direction of the correlation implies that infants with lower soothability ratings had larger (more positive) P400 amplitude to fearful faces, relative to neutral faces. Again, this correlation maintained even after controlling for infant gender (*r* = -.262, p = 036).

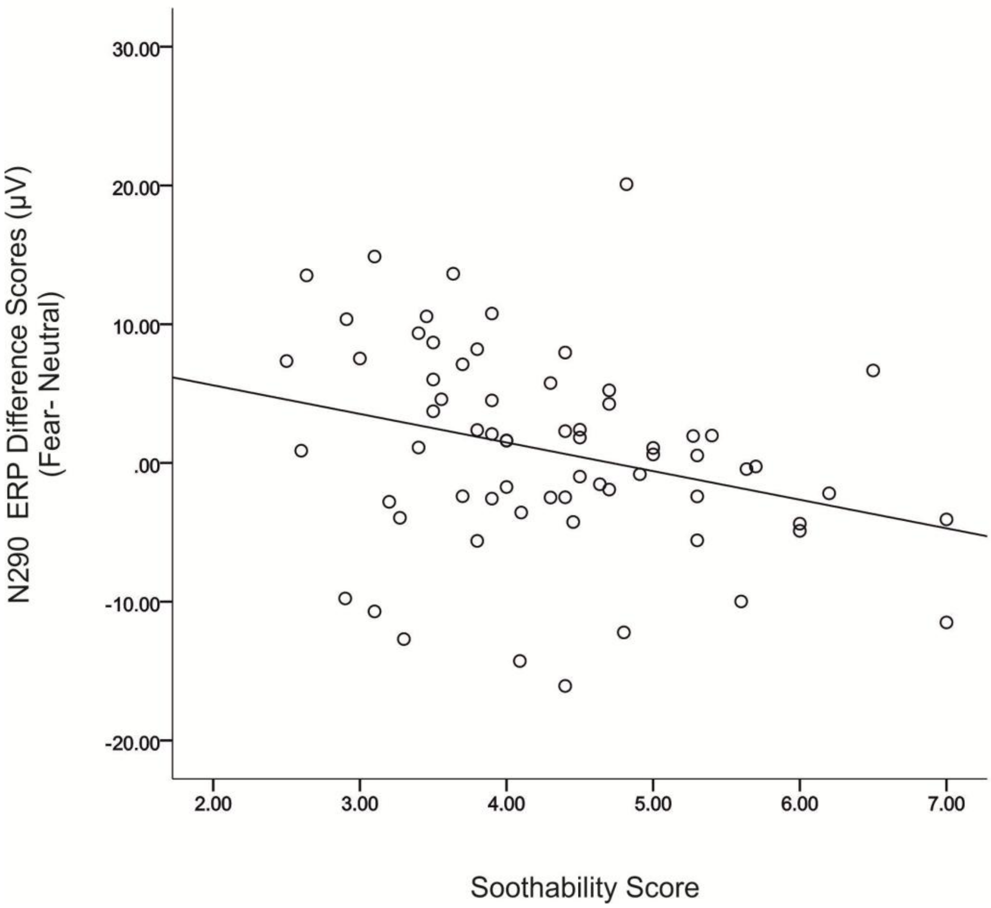
Figure 3-3 Scatterplot P400 and Soothability



3.3.4 Effects of Infant Temperament on the N290 ERP Component

There were no significant main effects or interactions for the composite score of *negative emotionality/reactivity*. When *Soothability* was included as a continuous covariate there was a statistically significant main effect of emotion ($F_{2,126}$ = 4.598, *p* =.012, η_p^2=.068). The main effect of laterality was not significant ($F_{1,63}$ = 1.537, *p* =.220, η_p^2=.024). In addition, there was a statistically significant emotion x *Soothability* interaction ($F_{2,126}$ = 4.006, *p* =.021, η_p^2=.060). Again, using the previous mentioned ERP difference scores, follow up analyses found a significant correlation between *Soothability* and the N290 amplitude for fearful faces, relative to neutral (*r* = -.284, *p* = .022). The direction of the correlation implies that infants with higher soothability ratings, as opposed to lower soothability rating as in the Nc and P400 results, had a larger (more negative) N290 amplitude to fearful faces, relative to neutral faces. Again, this correlation maintained even after controlling for infant gender (*r* = -.287, p = .021).

Figure 3-4 Scatterplot N290 and Soothability



A multiple regression was run to assess whether each of the three ERP components were independent at predicting soothability scores. Soothability scores were entered as the dependent variable with fear minus neutral face amplitudes for the Nc, P400 and N290 entered as the independent variables. The model was marginally significant F(3,61) = 2.41, p = .076, R^2 = .106, but all three independent variables became non significant, suggesting that the associations reported previously may indicate overlapping effects representing a common set of associations characteristic of infants who score low on soothability.

3.4 Discussion

The role that early temperament plays in predicting future development is an important area of research. These traits, influenced strongly by genetics, but also shaped by the environment appear to play a vital role in emotional and social development (see Rothbart, et al., 2006). An individual's temperamental disposition, in particular affective dimensions such as negative affect and affect regulation appear particularly relevant. Understanding the neurobiological mechanisms that may relate to such behavioural dispositions seems an important step. As such, the aim of this study was to assess whether differences in temperament in early infancy are related to neural responses that are specifically involved in emotion processing.

Before testing the role of infant temperament in relation to emotion processing, we began by confirming that the infant emotion processing ERP components typically reported in other studies could be observed in our data. As expected, the results lent further support to the existing research base which demonstrates that by 7 months of age, infants display reliable differences in their ERP responses to emotional expressions. Specifically, the most studied infant ERP component, the Nc, displayed higher amplitudes in response to fearful faces compared to happy and neutral emotional expressions in this sample, consistent with several past investigations (De Haan, et al., 2004; Leppänen, et al., 2007; Nelson & De Haan, 1996; Peltola, et al., 2009). In contrast, the infant N290 and P400 ERP components did not differentiate between facial displays of emotion. Only two studies to date have identified an emotion effect on the N290 component, with contradictory results (Hoehl, et al., 2008; Kobiella, et al., 2008). As such, the lack of emotion effect found at these two components is not unexpected.

Most importantly, for all three components, the Nc, the P400 and the N290, a statistically significant interaction appears when the subscale *soothability* is factored in with relation to emotional faces. Specifically the Nc and the P400 displayed increased neural activity (i.e. greater amplitude) to fearful faces (relative to neutral faces) for those infants who were rated as being *harder* to soothe. However, the N290 displayed larger amplitudes in response to fearful faces for those infants who were rated as *easy* to sooth, as opposed to harder to soothe as seen in the Nc and P400 results. It is also important to note that the regression analysis indicated that there may be an overlapping effect between all three components possibly suggesting a common set of associations characteristic of infants who score low on soothability.

As previously addressed, the temperamental dimension *soothability* can be seen to represent self-regulatory temperamental traits. The term soothability within the *Infant Behaviour Questionnaire* refers to how well the parent feels their infant responded to soothing techniques employed by the parent to reduce negative affect displayed by the infant. Examples include, “did the baby soothe by being spoken to?” and “did the baby soothe by offering baby his/her security object?” It is assumed that infants who are harder to soothe will display more negative affect and behaviour, such as crying and fussing (Blum, Taubman, Tretina, & Heyward, 2002; Stifter & Fox, 1990). Empirically, low levels of soothability have been associated with greater difficulties in attention disengagement from aversive stimuli (Leppänen et al., 2011) as well as with insecure attachment (Mills-Koonce, Propper, & Barnett, 2012). Two broad interpretations of the results reported in this study are worth considering. Firstly, infants who are regarded as being harder to soothe can be seen as having difficulties in regulating their emotions (Rothbart, et al., 2011). Low levels of self-regulation, in particular emotion regulation, are more likely to be accompanied by negative behaviours such as fearful inhibition, anger, fretting and crying. Temperamentally, such infants are more sensitive to heightened levels of arousal and expressed negative emotion (De Haan, et al., 2004). Empirical data by Leppanen and colleagues (2011) show that infants who were regarded as harder to soothe had more difficulties in disengaging from aversive stimuli. This lack of attention disengagement has been argued to reflect a deficit in regulatory processes, as it has been suggested that an individual's ability to turn away from aversive stimuli serves as a function to reduce negative affect (Leppänen, et al., 2011; Rothbart, Ellis, Rosario Rueda, & Posner, 2003). Arguably, the increase in neural activity to negative emotional stimuli reported in this study could be seen as reflective of this heightened sensitivity and inability to disengage from negative emotion. Given that there is strong evidence for the infant Nc (Richards, 2003; Vaughan Jr & Kurtzberg, 1992) and some more limited evidence for the infant P400 (Carver, et al., 2003; Dawson et al., 2002) representing allocation of attention, it is possible to assume that the infants in this study, who are regarded as having difficulties in regulatory abilities, are in fact struggling to reduce their attention from negative stimuli. Future research would benefit from looking at both ERPs and attention disengagement data to negative emotional stimuli to substantiate this cross-over.

Our findings are broadly consistent with the evidence presented by de Haan and colleagues (2004) in which they found infants scoring higher on negative affect showed increased neural responses to fearful faces on the Nc. However, although soothability is linked to expressed negative emotion, it is by no means a direct assessment of negative emotionality, and as such our finding is clearly not an exact replication to those reported by De Haan (2004). It is also notable that our findings are in direct contrast to Martinos et al. (2012) who showed that infants who scored higher on self-regulatory traits had increased neural responses to fearful faces at the Nc. Two reasons are possible for this discrepancy. The first is that Martinos et al. studied infants from 3 to13 months old, while this investigation focused on infants who were 7 months of age. It is widely accepted that self-regulatory behaviours develop over the course of the first two years, with older infants displaying more regulatory behaviours than younger infants

(Kochanska, Coy, & Murray, 2001; Kopp, 1982). As previously mentioned, it is argued that this is partly due to the maturation of the frontal lobe structures thought relevant for effortful control of attention, aiding self regulation (Rothbart, et al., 1994; Rueda, et al., 2004). As the Martinos et al. study includes such a broad range of ages their findings are difficult to interpret and may reflect a mixture of effects operating at different ages. Secondly, Martinos and colleagues used a more detailed composite of self regulation incorporating other sub-scales besides *soothability*, such as Cuddliness/Affection and Low Intensity Pleasure scales. This inevitably could have led to a more comprehensive understanding of self-regulation than our study managed to achieve.

A second interpretation of our finding of greater neural responses to negative emotion for harder to soothe infant's, rests on the possible interplay between emotional expressions in the infants environment and the child's neural development. Frequent displays of negative affect expressed by harder to soothe infants may cause the parent to display increased levels of negative expressions. A parent struggling to deal with their infant's inability to be soothed may result in more negative facial expressions. This is plausible, given the evidence that children deemed as having a difficult temperament can effect a parent's behaviour, specifically with an increase in negative parenting (Kiff, Lengua, & Zalewski, 2011; Lengua, 2006). Infants who appear more difficult by their parents may therefore increase parents' levels of stress, resulting in more frequently displays of negative emotion from the parent. This idea is strengthened by the work of Ghera and colleagues (2006) who showed that mothers' perceptions of their infants' ability to be soothed, moderated the predicative relationship between infants' level of negative reactivity and maternal sensitive caregiving. In other words, infants who were seen as negatively reactive and judged to be harder to soothe by the parents resulted in the parent being less sensitive. Another possibility is that mothers of infants who are more prone to negative affect mirror their infant's facial expressions (A. Atkinson &

Adolphs, 2005; Niedenthal, Brauer, Halberstadt, & Innes-Ker, 2001; Oberman, Winkielman, & Ramachandran, 2007; Rapson, Hatfield, & Cacioppo, 1993), which in turn leads to greater exposure to such facial expressions. As such, our findings of increased neural activation to fearful faces for the Nc and P400, for those infants who are harder to soothe, could be due to a sensitisation to fearful faces as a result of exposure. This explanation is given weight by evidence indicating that the Nc in particular has been shown to be sensitive to familiar stimuli (De Haan & Nelson, 1997, 1999). Such an interactive process would be interesting to pursue in greater depth in future research in light of the evidence of impaired socio-emotional traits in children who experience parents that react negatively to their children's displays of negative emotions (Eisenberg, Fabes, & Murphy, 1996; Gottman, Katz, & Hooven, 1996).

Heightened neural processing of negative emotions may be an important early-appearing marker for risk for affective disturbance in later development. Certainly, hyper-vigilant response to negative displays of emotion has been observed in a range of clinical groups, such has maltreated children and institutionalised children (Maheu, et al., 2010; McCrory, et al., 2013; McCrory, et al., 2011; Tottenham, et al., 2011). Specifically, maltreated children have showed heightened neural responses to angry facial expressions (Pollak, et al., 1997; Pollak, et al., 2001; Shackman, Shackman, & Pollak, 2007) and institutionalised children displaying increased neural activation to fearful faces (Parker & Nelson, 2005; Tottenham, et al., 2011). This increased neural activation seen in clinical populations to these social signs of threat are hypothesised to be an adaptive mechanism that allows for quick detection, to ensure a swift response which protects the individual (Shackman, et al., 2007). Arguably, this hyper-vigilance potentially can lead to a flight response that ultimately calibrates their heightened fearful arousal. A direct comparison cannot be attempted in reference to the data presented in this study to the clinical findings above. However, it is apparent that heightened neural responses to threat-related stimuli are possibly connected to regulatory functioning and as such, given the infants in this study who can be seen to be struggling to regulate their affect, useful parallels may also be drawn.

Another interesting finding in this study that is worth addressing is the reverse effect found at the N290 component. Infants who were *easier* to soothe in fact had increased amplitudes on the N290 to fearful faces relative to neutral facial expressions. As mentioned in chapter 2, empirically the N290 is considered to be a precursor to the adult face sensitive component the N170. The defining feature of the N290 is its structural encoding of face stimuli (De Haan, et al., 2002; Halit, et al., 2003). In particular, face stimuli elicit larger responses on the N290 (De Haan, et al., 2002). The result from this study for this early face detection component are interesting as it is possible to hypothesise that those infants who are easier to soothe are less familiar with the structural makeup of a fearful face. This interpretation would be consistent with the evidence that has shown the N290 to be sensitive to unfamiliar stimuli (Righi, et al., 2014). As such, it can be argued that the infants in this study are allocating more neural resources to encoding the features of negative emotion. Thus, it becomes possible to contemplate whether those infants who are harder to soothe are in fact more used to encoding the features of negative expressions more than those infants who are easier to soothe. This interpretation would lend support to the idea that these harder to soothe infants are in fact more exposed to expressed emotions of negativity.

Following this train of thought it becomes possible to relate the current findings to parenting programs designed to promote positive parenting in response to infant behaviour. Specifically, if one assumes that the data presented, in which there is a heightened neural sensitivity to negative emotion for infants who are harder to soothe, is a reflection of possible increased exposure to negative emotion (perhaps in response to unsoothable behaviour) from the parent, then parenting programs that aim to help parents deal with their child’s increased arousal would be particularly beneficial. Helping parents to manage these affective goal conflicts within the relationship may equip the parent with the necessary regulatory tools needed to deal with their infant’s heightened arousal without exposing them to negative emotion.

3.5 Limitations

This study has a number of limitations. Firstly, the IBQ questionnaire is a parent reported measure and although robustly validated may still be subjected to error and respondent bias. For example, evidence indicates that parents’ responses to temperament questionnaires depend in part on their current life stressors (Räikkönen et al., 2006), and hence may be influenced by their mood. Secondly, due to participant demand and time constraints this study used the original, and shorter, IBQ, rather than the IBQ –Revised (R). The IBQ-R includes up to 191 questions as opposed to the 94 of the IBQ. These additional questions result in further subscales of infant temperament including falling reactivity, cuddliness, perceptual sensitivity, sadness, approach, and vocal reactivity providing a much richer and detailed look at infant temperament. Future studies would benefit from a fuller examination of infant temperament including possibly a laboratory based approach to assessing temperament, when measuring its effects on emotion processing.

Arguably, the *soothability* subscale is a dyadic dimension, in a sense it is assessing co-regulation. The parents are rating their child’s response to their own attempts at soothing behaviours. As such, it is possible to argue that the *soothability* subscale is in fact assessing something more than just a dimension of infant temperament. With this in mind, identifying the causal pathways of both the parent and the child behaviours becomes problematic, i.e. is it the parents response that is increasing the infants distress or is it the infants distress causing a particular response in the parent. Given the mediating role that parenting plays in the expression of temperament (Hinde & Stevenson-Hinde, 1987; Putnam, et al., 2002; Rubin, et al., 2001; Sanson, et al., 2011; van den Boom & Hoeksma, 1994) attributing the results from the *soothability* subscale to infant temperament, or at least purely endegenous characteristics, alone may be overly simplistic. Further investigations into parental interactive styles, infant temperament and their mutual or interacting effects on emotion processing would prove beneficial in future research.

3.6 Summary and Conclusions

Seven month old infants are able to neurologically distinguish between displays of expressed emotions. Furthermore, the neurological processing of emotion in 7 month old infants is related to individual differences in temperament. This research shows that *self regulatory* behaviours, such as soothability, are correlated to ERP amplitudes to emotional faces. Specifically, increased neural responses to fearful faces for the Nc and P400 ERP components were related to infants who were regarded as being harder to soothe. Whereas infants who are considered as easy to soothe displayed greater amplitudes to fearful faces (relative to neutral) on an early face processing ERP component, the N290.

In conclusion, this investigation confirmed that not only are the neural networks associated with emotion processing in place for 7 month old infants but that these neural mechanisms are influenced by individual traits of temperament. Specifically, parents' ratings of levels of soothability that their infants display are related to the neural processing of negative emotion. An early face detection component is appearing sensitive to possible novelty features of faces, with infants who are regarded as easy to soothe displaying greater neural activation to negative emotion. While later ERP components are showing an increased sensitivity through greater neural activation to negative emotion, for those infants regarded as harder to soothe. Although this study lends support for the influence of temperament on an infant's neural processing of emotion, the temperamental dimension that is seemingly influential includes a dyadic element. As such, it is arguable that an individual's temperament is not the sole influence in their neurological processing of emotion but rather a combination of temperament and parental influence is at play.

4 The Effects of Maternal Mental Health on Infants' Neurological Processing of Emotion

The overriding conclusion from chapter 3 suggests that although infants' temperamental disposition is influential in the neural processing of emotion it appears that the dyadic elements inherent in the parent-infant relationship in regulating temperamental traits may play an important factor in relation to emotion processing. As such, chapter 4 will focus on parental contributions to infant's neural processing of emotion by examining mothers' mental health and the processing of emotion in their offspring. There is extensive evidence that maternal mental health problems, particularly depression, affects the quality of interactions occurring within the parent-child relationship, and impacts on the child's longer-term social and emotional development (e.g. Cummings & Davies, 1994; Goodman & Gotlib, 1999; Murray & Cooper, 1997). Maternal mental health is thus a good marker for disturbances within the mother-child relationship. The proposed study aims to assess the extent to which variations in maternal mental health relate to individual differences in infants' neural processing of facial emotional expressions. Specifically, this chapter will look at levels of self -reported maternal depression, as well as maternal anxiety and parental stress in relation to infants' Event Related Potentials (ERPs) in response to fearful, happy and neutral facial expressions. The intention of this investigation is to not only add to the existing literature that suggests facial emotion-related brain systems are influenced by social experience, but in particular by maternal mental health.

4.1 Introduction:

The effects of maternal mental health on a child's emotional and social development have been the focus of developmental research for some time. Specifically, affective disorders such as parental depression have consistently been related to later child development (e.g. Cummings & Davies, 1994; Goodman & Gotlib, 1999; Goodman, et al., 2011; Murray & Cooper, 1997).

The postpartum period is clearly a vulnerable time for affective disorders to emerge. Maternal depression occurs in 10-15% of pregnancies and in the postpartum period (O'Hara, Zekoski, Philipps, & Wright, 1990), with depression rates at their highest in women of childbearing age (Kessler, McGonagle, Swartz, Blazer, & Nelson, 1993). In addition to this, postnatal anxiety is also prevalent during this time, in the range of 8 to 17% of women who have recently given birth (Matthey, Barnett, Howie, & Kavanagh, 2003; Miller, Pallant, & Negri, 2006; Reck et al., 2008; Wenzel, Haugen, Jackson, & Brendle, 2005). The impact that such mental health difficulties have on the developing parent-infant relationship is substantive. As a result, disruptions in infant social and emotional functioning can occur from very early on, with prompt identification of these problems being crucial for effective intervention (Briggs-Gowan, Carter, Irwin, Wachtel, & Cicchetti, 2004; Glascoe, 1997, 2000; Squires, Bricker, Heo, & Twombly, 2001).

Children living with a parent who is experiencing clinical depression are often exposed to atypical parent–child interactions on a daily basis (Lovejoy, 1991). Specifically, depressed mothers are unable to provide attuned responses to help regulate their infants heightened arousal and have been shown to be less able to imitate and elaborate infants facial expressions and gestures (Brazelton, Koslowski, & Main, 1974; Papoušek & Papoušek, 1987). Overall, depressed mothers tend to demonstrate less synchrony and are more insensitive in their interactions with their infants (Beck, 1995; Field, Healy, Goldstein, & Guthertz, 1990; Murray & Cooper, 1996). These disturbed interactions can be manifested behaviourally as either a hostile, angry and intrusive parent or at the other end of the spectrum a withdrawn, flat and disengaged parent (Cohn, Campbell, Matias, & Hopkins, 1990; Goodman & Brumley, 1990; Lovejoy, 1991; Lovejoy, et al., 2000). Parents who are experiencing less severe episodes of depression have also been shown to respond in a less optimal way towards their infants signals (Stanley, Murray, & Stein, 2004), display less affection (Ferber, Feldman, & Makhoul, 2008; Herrera, Reissland, & Shepherd, 2004) and have poorer communication skills (Bettes, 1988; Kaplan, Bachorowski, Smoski, & Zinser, 2001) when interacting with their infants. As such, it is now firmly accepted in the developmental field that maternal depression is a major risk factor for children's healthy social-emotional growth, with the effects of maternal depression on a child being observed in early infancy and continuing through to late adolescence and on to adulthood.

Observational evidence suggests that newborn infants of depressed mothers are more irritable, less consolable (Whiffen & Gotlib, 1989) and less responsive to stimulation (S. Abrams, Field, Scafidi, & Prodromidis, 1995). Furthemore, infants of depressed mothers show more negative affect than postive affect when interacting with both strangers (Field, et al., 1988) and their own mothers (Cohn, et al., 1990; Field, 1984). In the early years of a child's life, maternal depression has been linked with lower rates of secure attachment (C. Martins & Gaffan, 2000; van IJzendoorn, Goldberg, Kroonenberg, & Frenkel, 1992), increased dysregulated aggression, heightened emotionality, increased negative affect and more self directed regulatory behaviours (Field, 1992; Tronick & Gianino, 1986; Zahn-Waxler, Cummings, McKnew, & Radke-Yarrow, 1984). Continuing into childhood, children of depressed mothers tend to have more difficulty with social interactions and social anxiety becomes more prevalent, with an increase in social phobia and separation anxiety in particular (Orvaschel, Walsh-Allis, & Ye, 1988; Weissman, Leckman, Merikangas, Gammon, & Prusoff, 1984). Externalising problems can emerge in early childhood, becoming apparent through increased attention deficit and disruptive disorders (Biederman, et al., 2001; Luoma, et al., 2001; Zahn-Waxler, et al., 1990), more aggressive play (particularly in males) with peers (Hipwell, Murray, Ducournau, & Stein, 2005) and higher rates of social exclusion (Cummings, Keller, & Davies, 2005). Cognitively, children of depressed mothers tend to have lower levels of intelligence and poorer academic achievements (Anderson & Hammen, 1993), with their self worth and self concept being lower (Hammen & Brennan, 2001; Jaenicke, et al., 1987). Furthermore, they have a tendency to blame themselves more for negative outcomes (Hammen & Brennan, 2001; Jaenicke, et al., 1987). Children of depressed mothers are ultimately at greater risk of developing childhood depression themselves (20-40%; Beardselee, Versage, & Giadstone, 1998; Hammen, Burge, Burney, & Adrian, 1990; Weissman et al., 1987). Not only do these children show earlier onsets of depression but are more likely to experience depression for a longer duration and have a higher chance of reoccurrence, compared to children who develop depression without a parent who suffers from depression (Hammen & Brennan, 2003; Hammen, et al., 1990; Keller et al., 1986; Warner, Weissman, Fendrich, Wickramaratne, & Moreau, 1992).

Research looking at the effects of postnatal maternal anxiety on child outcomes is less comprehensive than that of maternal depression but nonetheless is worthy of mentioning. The majority of research in this field focuses on parent-child interaction, with a particular focus on parental behaviour. It appears that common behaviours among mothers with anxiety disorders tend to be that they are more critical, catastrophize more, are less granting of autonomy and ultimately less sensitive in their interaction with their child (Feldman et al., 2009; Rapee & Heimberg, 1997; - except for Turner, Beidel, Roberson-Nay, & Tervo, 2003; Whaley, Pinto, & Sigman, 1999). In fact one study by Hirshfeld and colleagues (1997), reported a direct association between maternal anxiety, maternal criticism, and child behavioural inhibition and psychiatric disorders. Both postnatal and prenatal anxiety have been significantly related to externalising behaviour problems in offspring, in particular ADHD (O'Connor, Heron, Golding, Beveridge, & Glover, 2002; Van den Bergh & Marcoen, 2004). Postnatal anxiety has also been seen to correlate with less social engagement in infancy (Feldman, et al., 2009). Finally, evidence suggests that children who have a parent experiencing an anxiety disorder are significantly at greater risk of meeting the criteria themselves for childhood anxiety (Beidel & Turner, 1997; Capps, Sigman, Sena, Heoker, & Whalen, 1996; Whaley, et al., 1999).

Both maternal depression and anxiety are often considered to be manifestations of experienced parental stress (Benson & Karlof, 2009) but parental stress is by no means restricted to these two factors. Parental stress is defined as "the aversive psychological reaction to the demands of being a parent" (Deater-Deckard, 1998; p. 315). Higher levels of reported parental stress have consistently been related to poor parenting. In particular, parents who report increased levels of stress are more likely to be harsh, negative and more authoritarian in their response (Belsky, Woodworth, & Crnic, 1996; Conger, Patterson, & Ge, 1995; Rodgers, 1993). Social interaction between parent and child tends to be more limited (Adamakos et al., 1986; McBride & Mills, 1993) and insecure attachment styles are prevalent among parents reporting high levels of parenting stress (Jarvis & Creasey, 1991; Teti, Nakagawa, Das, & Wirth, 1991). Most importantly, higher levels of parental stress are considered to be a vital factor in the development of child abuse (Chan, 1994; Holden & Banez, 1996). The impact that poor parenting, associated with parenting stress, has on a child's social and emotional development is broad. There is evidence to suggest that self-reported levels of parental stress are associated with a child's level of social competence (Cappa, Begle, Conger, Dumas, & Conger, 2011), their empathic responding (Denham & Grout, 1993; Denham, et al., 1994) as well as an increasing both externalising and internalising behavioural problems in their offspring (Anthony et al., 2005; Neece, Green, & Baker, 2012).

The enduring effect of maternal mental health on a child's successful emotional growth is substantiated. It is clear that the interactive style between a mother with symptomatic behaviours and their child is largely at play in the development of successful emotional and social functioning. Of particular relevance to this thesis, a handful of studies have considered the effects of maternal mental health in relation to a child's social and emotional development by directly studying their processing of socially and emotionally relevant stimuli.

To begin, it has been shown that infants of depressed mothers compared to non-depressed mothers orient less towards human faces and voices in the first month of life (Hernandez-Reif, Field, Diego, & Ruddock, 2006). Furthermore, when infants of depressed mothers compared to infant of non-depressed mothers are shown face/voice pairing from their mother and a stranger, the infants of depressed mothers required more trials, took twice as long to habituate to face/voice pairs of their mothers and were unable to discriminate between their mother's face and a stranger's (Hernandez-Reif, Field, Diego, & Largie, 2002). Infants of non-depressed mothers compared to depressed mothers have also been to shown to differentiate in their attentive responses to the sound of other infants' cries. Specifically, infants of non-depressed mothers showed a reduction in heart rate and less sucking activity when they were exposed to other infants' cries compared to a lack of change in these responses for those infants with depressed mothers (Field, Diego, Hernandez-Reif, & Fernandez, 2007). This lack of a change in the infants of depressed mothers attentive responses has been suggested as a possible precursor to non-empathic behaviour witness in older children of depressed mothers (Jones, Field, & Davalos, 2000).

Further yet in non-contingent maternal behaviour paradigms, infants of depressed mothers show less distress responses and fewer negative expressions, such as less frowning, at incongruent behaviours (Field, Hernandez-Reif, et al., 2007; Field et al., 2005). In particular, during a still-face paradigm the infants of depressed mothers not only showed less distress than you would normally see in a control group but they also show less interactive behaviour during the return to spontaneous play (Field, Hernandez-Reif, et al., 2007). Finally, in regards to direct exposure to emotional expressions, infants of depressed mothers compared to those of non-depressed mothers have been shown to take longer to habituate to positive emotional expressions (Hernandez-Reif, Field, Diego, Vera, & Pickens, 2006). Interestingly, in this habituation study the infants of depressed mothers were able to discriminate between happy and sad facial expressions but only if they were habituated to sad faces first (Hernandez-Reif, Field, Diego, Vera, et al., 2006). However, a more recent study showed that even after infants of depressed mothers were habituated to sad and neutral facial expressions the infants were unable to discriminate between the facial expressions later on (Bornstein, Arterberry, Mash, & Manian, 2011). Furthermore, looking time data has shown that infants of depressed mothers show a preference for looking at smiling faces and display decreased attentional disengagement to fearful facial expressions (Forssman et al., 2014). Collectively, the above studies that observe infants behaviour in direct response to emotional and social stimuli highlights the interplay between maternal mental health and infants sensitivity in the perceiving and processing of emotional information.

The observational evidence that looks at the effects of maternal mental health on child emotional and social outcomes is relatively consistent. Further yet, there is now growing evidence that can index differences in behavioural responses directly to emotionally relevant stimuli in early development. This useful behavioural evidence has led researchers to investigate how these effects on child behaviour are manifested in differences in brain development and functioning that are related to emotional development. As such, there has been a surge of interest to investigate the biological impact that maternal mental health may have on their offspring neurophysiological systems that might be responsible for the emotional and social consequences associated with mental health issues.

A number of studies have assessed neuroendocrine function in children of depressed mothers. Glucocorticoids – cortisol, is one of the end products created by heightened activity of the hypothalamic–pituitary–adrenocortical (HPA) axis and is commonly known as the stress hormone. The HPA axis is thought of as an evolutionary adaptive system relevant in dealing with stressful events (Ursin, Murison, & Knardahl, 1983), with dysfunctional activity linked to various mood disorders, such as depression and anxiety (Faravelli et al., 2012; Pariante, Thomas, Lovestone, Makoff, & Kerwin, 2004). Human offspring of mothers suffering from depression or a comorbid of depression and anxiety have been shown to have elevated levels of baseline cortisol and heightened cortisol reactivity (Azak, Murison, Wentzel-Larsen, Smith, & Gunnar, 2013; Essex, Klein, Cho, & Kalin, 2002; Lupien, King, Meaney, & McEwen, 2000). The enduring effects of postnatal depression on a child's cortisol secretion has been shown to expand from infancy through to the preschool years (Bugental, Martorell, & Barraza, 2003; Essex, et al., 2002). Interestingly, 13 year old children, of postnatally depressed mothers, cortisol levels were predicted by a distinct parenting style of withdrawal behaviour that occurred during infancy (Murray, Halligan, Goodyer, & Herbert, 2010). In addition, animal studies have provided further supported for the sensitivity of the HPA axis to rearing conditions (Champagne, 2008; Levine, 2005). It is suggested that chronic elevated levels of cortisol is reflective of a deregulated HPA axis, with prolonged levels of heightened cortisol being shown to affect brain atrophy, specifically hippocampal volumes (Lupien et al., 1998). Prolonged levels of heightened HPA activity is thought to be particularly problematic during an infant's early years as evidence from animal studies suggests that infancy is a critical period in the development of the HPA functioning (Macrì & Würbel, 2006). Furthermore, alterations in HPA functioning in children have been directly associated with a range of socio-emotional consequences, specifically, childhood depression (Guerry & Hastings, 2011; Lopez-Duran, Kovacs, & George, 2009) and externalising behavioural problems (Alink et al., 2008).

In regards to neurological development, a recent longitudinal study looked at the effects of maternal depressive symptomology and 10-year-old children's regional brain volumes, in a sample of children who had experienced mothers with depressive symptomology from birth (Lupien, et al., 2011). These authors reported no differences in hippocampal volume between offspring of mothers with depressive symptomology versus control. They did, however, find larger left and right amygdala volumes. Both the hippocampal and amygdala results are supportive of previous animal studies involving poor maternal care (Kikusui, Ichikawa, & Mori, 2009; Ono et al., 2008) as well as studies with children in institutional care settings (Mehta, et al., 2009; Tottenham et al., 2010). Furthermore, a direct correlation between mean maternal depressive scores and amygdala volumes emerged, with higher depression scores reflecting larger amygdala volumes in their offspring (Lupien, et al., 2011). These findings are intriguing, given the crucial role that the amygdala plays in social and emotional development (Payne & Bachevalier, 2009). Despite these impressive findings, this study is longitudinal in nature and as such does not further our understanding of the impact that maternal mental health has on the early development of such emotion related neural systems, especially considering that the amygdala is thought to be fine-tuned over the first few years of life (Belsky & De Haan, 2011).

The most converging evidence for infant neural development in relation to maternal mental health comes from neuroscientific studies focusing on cortical activity in the prefrontal cortex in the infant, in particular, maternal depression and asymmetric differences in infants' electrical brain activity. There is now substantial evidence to suggest that infants of depressed mothers have a distinct physiological profile of greater relative right frontal EEG activation than infants of non-depressed mothers (Dawson et al., 1999; Dawson, et al., 1992; Field, 1995; Jones, et al., 2009; Jones, Field, Davalos, et al., 1997). A useful meta-analysis in 2006 substantiated this association (Thibodeau, Jorgensen, & Kim, 2006). Further yet, greater right frontal activity for children of depressed mothers has been shown to be stable from early infancy through to 3 years of age (Jones, Field, Fox, et al., 1997) and has been shown to remain present during interactions with others as opposed to just with their depressed mothers (Dawson, et al., 1999). This hemispheric bias has been associated with emotion regulation, negative affect, stress reactivity and withdrawal behaviour (Davidson, 1995; Fox, 1994a; Henderson, et al., 2001). Distinct depressive styles, such as withdrawal and intrusive parenting have also been suggested to have distinct neurophysiological correlates as measured by electrical brain asymmetry. For example, infants of withdrawn mothers have been found to display greater relative right frontal EEG activity than infants of intrusive depressed mothers (Diego, et al., 2006; Jones, Field, Davalos, et al., 1997; Jones, Field, Fox, et al., 1997).

This asymmetric difference between infants of depressed mothers and infants of non-depressed mothers has been addressed specifically in relation to the processing of emotion in two studies. Diego and colleagues (2004) investigated infants of depressed and non-depressed mothers frontal activity in relation to happy, sad and surprised facial expressions. Both groups of infants elicited greater relative right activity in response to sad facial expressions – a response deemed typical when processing negative emotion (Dawson, Hessl, & Frey, 1994) . However, infants of depressed mothers showed greater relative right frontal EEG asymmetry to all facial expressions. Interestingly, these infants also showed increased cortisol levels after the experiment. These results suggest that infants of depressed mothers are sensitive to a range of emotional expressions rather than just negative emotion. Furthermore, Diego et al. (2002) found that the specific behavioural manifestation of maternal depression (withdrawn and intrusive styles) accounted for asymmetric variation when viewing emotional faces in the infants as well. Specifically, infants of withdrawn mothers demonstrate little difference in their neurophysiological response to emotion by their mother or a female stranger but rather maintain their relative right EEG activity that they display during baseline. However, infants of intrusive depressed mothers displayed a shift towards greater right relative EEG activity during the viewing of sad facial expressions from a stranger. Again, this shift in electrical activity has been found to be associated with responses to negative stimuli observed in non-clinical populations (Dawson, et al., 1994). These two studies provide useful evidence for demonstrating the impact of different environmental experiences within the parent-infant relationship and its imprint on infants' neurological functioning relating to emotion processing.

Finally, the most converging evidence for the effects of maternal meant health on infants neural correlates deemed relevant in emotion processing comes from a very recent audio ERP study. Otte and colleagues (Otte, Donkers, Braeken, & Van den Bergh, 2015) assessed the effects of prenatal anxiety in relation to infants' ERP responses to emotional vocalisation after they had viewed an emotional facial expression. They found that infants, who are exposed to high levels of anxiety pre-birth, displayed larger ERP amplitudes to fearful vocalisations. The authors suggest that this increased neural activity, in response to fearful vocalisation, is indicative of the sensitivity to threat-related information that individuals who suffer from anxiety display. Although this study assesses pre-natal mental health in relation to infants neural processing of emotion rather than current experienced mental health it is arguably the strongest evidence relating maternal mental health to infants' neural responses specifically thought to be relevant in emotion processing.

The behavioural and biological research reviewed above provides good indicative evidence that maternal mental health may be associated with changes in brain function in infants related to emotional responding and emotion-processing. It can be suggested that these early appearing differences act as an indicator of risk in the development of later clinical difficulties. While it is important to note that the above findings may have an inherent genetic underpinning (O'Connor, McGuire, Reiss, Hetherington, & Plomin, 1998; Pike, McGuire, Hetherington, Reiss, & Plomin, 1996; Weissman, et al., 1984; Weissman, Sholomskas, Pottenger, Prusoff, & Locke, 1977), it is also plausible that the environment that the child experiences with the mother, and particularly the quality of parent-infant interactions, is contributing to such results.

There is limited evidence to date that looks at varying degrees of post-natal maternal mental health, outside of clinical diagnosis, in relation to infants specific neural responses deemed relevant in processing emotion. As such, the current study will explore neural responding linked to emotion processing by assessing infants' ERP responses to facial displays of emotion, and relate these neural findings to maternal symptoms of mental health. This investigation will specifically look at the empirically identified face and emotion sensitive infant ERP components, the N290, the P400 and the Negative Central (Nc). Given the literature reviewed above the following hypotheses are advance: (1) Infants of depressed and anxious mothers will show a neural sensitivity to positive emotion at the early-appearing face sensitive component, the N290 and (2) the same infants will show an increased sensitivity to negative emotion at the later face and emotion sensitive components the Nc and P400.

4.2 Method

4.2.1 Participants:

As explained in chapter 2, the sample for this study was drawn from a large database of parents from the community who agreed to be contacted regarding developmental studies. Participation was completely voluntary. For a full description of the recruitment procedure please see chapter 2. The sample in this study is the same sample of parents and infants that were presented in chapter 3. As in chapter 3, originally 130 seven month old infants (mean age 223 days, 69 males and 61 females) and their mothers out of the community sample database participated. All infants were born full term (i.e., 37-42 weeks) and of normal birth weight (>6 lbs, 2 oz). As in chapter 3, out of the 130, 71 infants had useable EEG data (mean age 231 days, 36 males and 35 females). The remaining 59 infants were excluded due to fussiness/inattentiveness and excessive ERP artefact including eye and body movement. This attrition rate is consistent with other infant ERP studies (De Haan, et al., 2004; Leppänen, et al., 2007). For a full sample description please see table 4.1. Out of the 71 infants, 69 mothers returned data on maternal depression, 68 mothers returned data for maternal anxiety and 65 returned information on levels of parental stress. The study was approved by University College London’s Research Ethics Committee.

Table 4-1 Sample Description

Sample Description N = 71
Mother age in years:

Mean (SD)	34.8 (4.3)
Range	20.7 - 50.4
Child age in months:	
Mean (SD)	7.7 (0.3)
Range	7.1 - 8.4
Child gender: N (%)	
Female	35 (49%)
Male	36 (51%)
Number of other children: N (%)	
First time mothers	54 (76%)
More than one child	14 (20%)
Missing	3(4%)
Mother ethnicity: N (%)	
White	60 (85%)
Black	1 (1%)
Asian	3 (4%)

Mixed	2 (3%)
Other	1 (1%)
Missing	4 (6%)
Mothers' education: N (%)	
Secondary School	2 (3%)
Further Education	5 (7%)
Higher Education	59 (83%)
Missing	5 (7%)
Mothers' Employment: N (%)	
Employment	55 (77%)
Unemployment	11 (16%)
Missing	5 (7%)
Household Income: N(%)	
Below £30,000 per year	5 (7%)
Above £30,000 per year	58 (82%)
Missing	8 (11%)

4.2.2 Measures:

The Center for Epidemiologic Studies Depression Scale (CES-D; Radloff, 1977): The CES-D was developed in the US to meet the demand for a quick measure of depressive symptoms in normative samples. The CES-D is a 20- item scale that measures depressive symptomology. During its development, items were selected from other depressions scales, including the Beck Depression Inventory (BDI), the Schedule for Affective Disorders and Schizophrenia (SADS) and the Minnesota Multiphasic Personality Inventory (MMPI). The major symptom areas that were identified included depressed mood, guilt/worthlessness, helplessness/ hopelessness, psychomotor retardation, loss of appetite, and sleep disturbance. The scale for each item ranges from 0 to 3 and is rated in terms of the frequency of occurrence during the past week. Total scores may range from 0 to 60, with a score of 16 and above indicating impairment. Although scores of 16 and over are considered as caseness for depression (Myers & Weissman, 1980) it is not a scale that can be used for clinical diagnosis. The reliability of the CES-D has been tested on clinical populations (Radloff, 1977) and on probability samples of US households (Radloff, 1977; Weissman, et al., 1977). The results from these investigations indicate that the CES-D scale has, acceptable test-retest stability and good construct validity for both clinical and community samples.

The State Trait Anxiety Scale (STAI; Spielberger, Gorsuch, & Lushene, 1970): The STAI assesses both state anxiety and trait anxiety. State anxiety relates to current feeling of anxiety in relation to specific event, i.e. how the person feels at that time. Trait anxiety reflects an everyday level of anxiety that a person may experience consistently over a period of time. The STAI is a self -report questionnaire that consists of 40 items. This thesis was interested in maternal levels of general anxiety and as such, focuses only on trait anxiety scores. Each question is rated on a 4 point likert scale consisting of the following for trait anxiety; 1) almost never, 2) sometimes, 3) often and 4) almost always. Scores range from 20 to 80, with higher scores indicating greater anxiety. Although there is no set cut-off for clinical diagnosis in the manual, previous studies have used a score of 39/40 (Kvaal, Macijauskiene, Engedal, & Laake, 2001) and

44/45 (Himmelfarb & Murrell, 1984). The STAI is appropriate for 6th grade reading level and has been used across a range of socio-economic backgrounds, in groups as well as individual assessment. The STAI is used commonly throughout research and clinical settings and has proved a useful tool at distinguishing between depression and anxiety. Excellent internal consistency coefficients for the STAI- T has been established average α = 89.With test-retest reliability average r =.88 (Barnes, Harp, & Jung, 2002). There is also considerable evidence that addresses the construct and concurrent validity of the STAI (Spielberger, 1989).

Parenting Stress Inventory – short form (PSI-SF; Abidin, 1995): The PSI is designed to assess the level of stress experienced in the parent-child relationship and to potentially identify dysfunctional dyads. The PSI:SF is a 36-item questionnaire that is measured on a five-point scale ranging from strongly agree to strongly disagree. In addition to a Total Stress score, three subscales are derived from scoring consisting of; 1) *The Difficult Child (DC),* this subscale assesses the degree at which parents perceive the level of difficulty in handling their child's behavior. *2) Parent-Child Dysfunctional Interaction (P-CDI)*, the primary focus of this subscale is to look at the degree to which parents are satisfied with their children's abilities to meet their expectations or not. *3) The Parental Distress (PD)* this subscale determines the level of distress a parent feels as a function of personal factors directly related to parenting. Parents who obtain a raw score above 90 for a Total Stress are considered to be experiencing clinically significant parental stress. Excellent internal consistency and concurrent validity of the PSI:SF subscales have been demonstrated with the full-length PSI (Abidin, 1995). A 6 month test-retest has highlighted the stability of the PSI:SF yielding an alpha of .84 for the Total Stress (Haskett, Ahern, Ward, & Allaire, 2006).

The CES-D and the STAI were both completed by parents at their homes prior to coming in for their infants' 7 - month visit. The PSI was completed before infants returned for a follow-up visit at 12 months of age. Parents were instructed to contact the researcher if they had any problems completing the measure or if they required any clarification on any of the questions asked. See table 4.2 for the sample summary of maternal mental health distribution.

Table 4-2 Descriptive Statistics for Maternal Mental Health Measures

	Completed Questionnaires N	**Mean (SD)**	**Range**	**Percentage for Clinical cut-off**
CES-D	69	14.7 (4.1)	6-26	39.1%
STAI	68	43.6 (11.4)	24-67	57.4%
PSI-SF	65	67 (14.4)	36-100	4.2%

4.2.3 Emotional Stimuli:

As previously described, the stimuli consisted of 5 female actors each posing a happy, neutral or fearful face. For each emotional expression (fear, happy and neutral) 70 still images were displayed, with a grand total of 210 faces. All images were posed against a white background and were cropped so no hair or other features could be seen. The stimuli were provided by the MacBrain Face Stimulus Set. Development of the MacBrain Face Stimulus Set was overseen by Nim Tottenham and supported by the John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development.

4.2.4 Procedure:

The procedure for the face viewing paradigm is the same as reported in chapter 3. Infants were seated on their parent's lap in an electrically shielded and soundproofed room at a viewing distant of 50cm from a 10.5 inches X 13.5 inches screen. The experiment consisted of one face viewing block. Each trial (emotional face) was randomly presented for duration of 750 milliseconds with the inter-stimulus interval being random between 500 and 1000ms. Infants' behaviour was monitored by a researcher through a video camera in the next room who activated a bright colourful animation with sound to redirect infants' attention to the screen if the infant became distracted. Trials would begin once infants' attention was drawn to the screen. When an infant's attention could no longer be redirected to the monitor the session was terminated. Parents were instructed to not interact with their infant at all during the session. Furthermore, that if their infant turned to look at them they were to avoid eye contact and look straight ahead. On average, session lasted about 20 minutes including, EEG net application, recording of 3 minutes of resting data and participating in the face viewing paradigm.

4.2.5 EEG recording:

The EEG recording is the same as that presented in chapter 3, EEG was recorded continuously through the face viewing trials using a 128 hydrocel geodesic net (Electrical Geodesic Inc. Eugene, OR) referenced to the vertex (Cz). The electrical signal was amplified with a 0.1-to 100-Hz band-pass with a sampling rate of 250Hz. All EEG data were analysed offline using the EEG platform EEGLAB (Delorme & Makeig, 2004) and in-house custom made MATLAB scripts.

4.2.6 Data Reduction:

For each participant the EEG signal was segmented into an epoch ranging from 100ms before stimulus onset and extending to 700ms after stimulus onset. Data were digitally filtered offline at a high-pass filter of 0.1Hz and a low-pass filter of 30Hz with bad channels being replaced using spherical spine interpolation. Visual inspection of the EEG segments was carried out to remove segments that had artefacts relating to eye and body movement or high frequency noise. Furthermore, the video recording of the infant was examined thoroughly and segments were rejected when the infant was not looking at the screen. Independents component analysis was run using FASTER to remove stereotyped artefacts (Nolan, et al., 2010).With a minimum of 10 trials per experimental condition data were averaged, re-referenced and baseline corrected. For the total sample of 71 infants, the average number of good trials was 21 for fearful, 22 for happy and 21 for neutral. As previously mentioned, this rate of data loss is consistent with other infant ERP studies (De Haan, et al., 2004; Leppänen, et al., 2007) and is not considered a threat to the validity of the experiment.

4.2.7 Statistical Analysis:

As previously mentioned in chapter 3, the following three infant ERP components were selected 1) Negative Central (Nc), 2) the P400 and 3) the N290. Time windows for all three infant ERP components, the Nc, P400 and N290 were created by examining the grand average waveform for all participants and looking at past studies' selected time windows.

Negative Central (Nc): As in chapter 3, the following central electrode clusters for each hemisphere was; left: 35, 41, 36, 47, 42 and right: 110, 104, 103, 93, 98. The time window selected for the Nc began at 350ms after stimulus onset and extend to 650ms after stimulus onset.

N290 and P400: As in chapter 3, the N290 and P400 electrode clusters consisted of left: 66, 70, 65, 69, 64 and right: 84, 83, 90, 95, 89. The time window selected for the P400 was 350ms after stimulus onset and extended to 600ms after stimulus onset. The N290 began at 250ms after stimulus onset and ended at 350ms after stimulus onset. See figure 4-2 for channel cluster locations.

Figure 4-1 Selected Channel Clusters

Negative Central (Nc) N290 & P400

Event Related Potentials: Analysis of amplitudes for all components, N290, P400 and the Nc, involved the use of mixed 2x3x2 ANOVAs. The within subject variables consisted of three emotional expressions (fearful, happy and neutral) and hemisphere (left and right). High and low scores for overall maternal mental health (depression, anxiety and parental stress) was entered as the between subject factor, The subscales on the PSI:SF, Parental Distress, Parent-Child Dysfunctional Interaction and Difficult Child, were also split into high and low scores and entered as between subject factors .

Maternal Mental Health: Using median splits, separate high and low scores were created for parents responses to all maternal mental health measures. For depressive symptoms, total scores from the CES-D resulted in high and low depressive symptoms groups (Mdn = 14, SD = 4.05). For anxiety symptoms total scores from the STAI resulted in low and high anxiety symptoms (Mdn = 41.50, SD =11.36) and for parental stress, total scores from the PSI:SF resulted in low and high total stress scores (Mdn = 66, SD = 14.44). As can be seen from tables 4-3 to 4-5, all three main groups were comparable in terms of maternal age, maternal education, current work status and infant gender.

Table 4-3 Maternal Depression

	Low Depression	**High Depression**	***t* (d.f.)**
Maternal Age	34.35 (4.41)	35.48 (4.21)	-1.03 (63)
	Low Depression	**High Depression**	**χ^2 (d.f.)**
Employment (employed)	*n* = 31 (86%)	*n* = 22 (79%)	.63 (1)
Education (degree)	*n* = 33 (92%)	*n* = 25 (89%)	.11 (1)
Infant Gender	Male =18 (49%)	Male = 18 (56%)	.40(1)

** $p < .01$.

Table 4-4 Maternal Anxiety

	Low Anxiety	**High Anxiety**	***t* (d.f.)**
Maternal Age	35.01 (3.57)	34.71 (5.13)	.28 (62)
	Low Anxiety	**High Anxiety**	**χ^2 (d.f.)**
Employment (employed)	*n* = 28 (85%)	*n* = 25 (83%)	.03 (1)
Education (degree)	*n* = 30 (91%)	*n* = 28 (93%)	.13(1)
Infant Gender	Male =16 (47%)	Male = 19 (56%)	.53(1)

** $p < .01$.

Table 4-5 Parental Stress

	Low Stress	High Stress	*t* (d.f.)
Maternal Age	34.89 (3.61)	34.64 (5.07)	.23 (61)
	Low Stress	**High Stress**	χ^2 **(d.f.)**
Employment (employed)	*n* = 25 (78%)	*n* = 26 (87%)	.77 (1)
Education (degree)	*n* = 29 (91%)	*n* = 27 (90%)	.01(1)
Infant Gender	Male =16 (50%)	Male = 18 (56%)	.39(1)

** $p < .01$.

4.3 Results

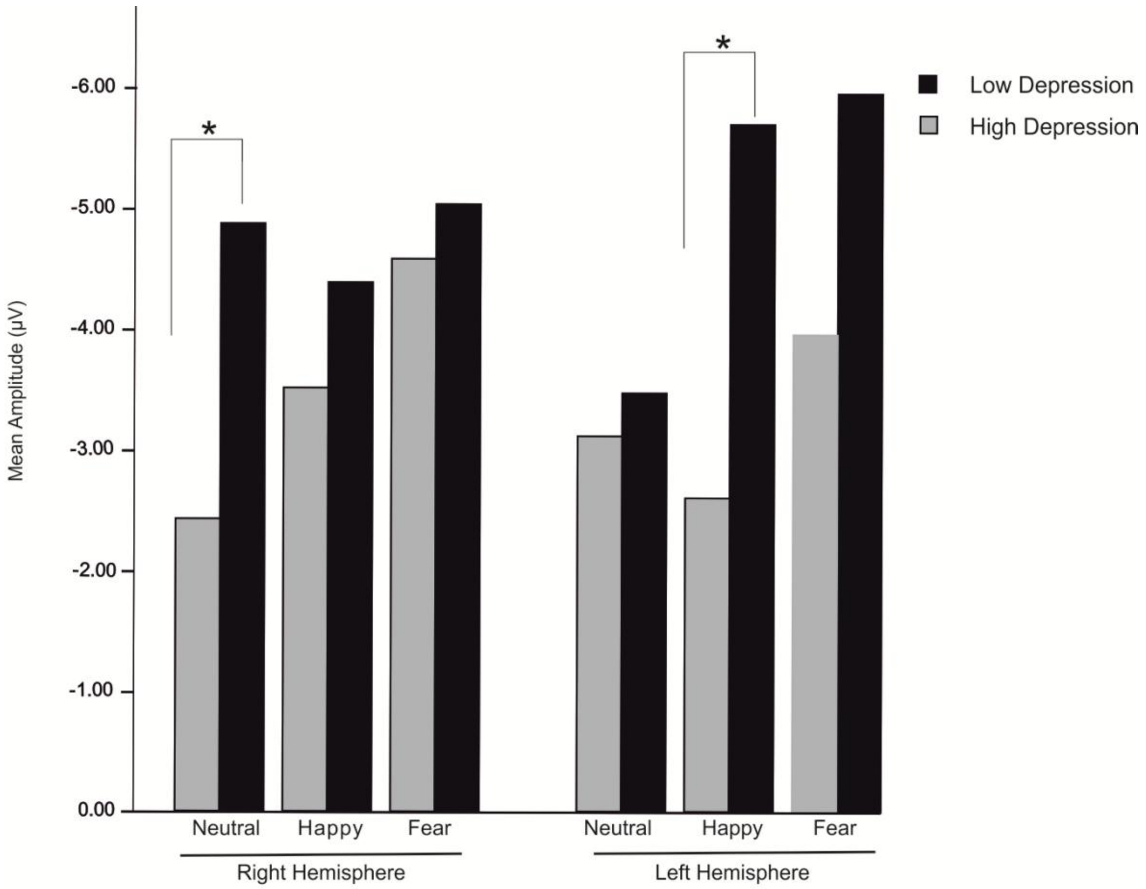
4.3.1 Effects of Maternal Mental Health on the Nc ERP Component

Depression: There was a statistically significant main effect of emotion on the Nc, ($F_{2,134} = 5.74$, $p = .004$, $\eta_p^2 = .079$). As expected, fearful face elicited larger amplitudes (-4.87) than positive (-4.04) or neutral (-3.46) facial expressions. The main effect of laterality ($F_{1,67} = .00$, $p = .99$, $\eta_p^2 = .00$) was not significant. The interaction between emotion and depression ($F_{2,134} = .45$, $p = .64$, $\eta_p^2 = .01$) and laterality and depression was not significant ($F_{1,67} = .14$, $p = .71$, $\eta_p^2 = .00$) . However, there was a three-way significant interaction between emotion, laterality and depression scores ($F_{1,134} = 3.62$, $p = .029$, $\eta_p^2 = .051$). Post-hoc comparisons between high and low depression scores were employed to probe this three-way interaction. Analysis revealed that infants of mothers with low depressive symptoms had greater (more negative) amplitudes to happy faces over the left hemisphere than infants of mothers with high depressive symptoms ($F_{1,67} = 5.14$, $p = .027$, $\eta_p^2 = .071$). Furthermore, infants of mothers with low depressive symptoms had greater amplitudes to neutral facial expression over the right hemisphere than infants of mothers with high depressive symptoms ($F_{1,67} = 5.07$, $p = .028$, $\eta_p^2 = .070$) See table 4-6 for descriptive statistics of the mean amplitude of the Nc.

Table 4-6 Depression and Nc Mean Amplitudes

Depression Scores	Emotion	Right Hemisphere Mean Amplitude	Left Hemisphere Mean Amplitude
Low Depressive Scores	Fear	-5.027	-5.943
	Happy	-4.379	-5.688
	Neutral	-4.865	-3.463
High Depressive Scores	Fear	-4.574	-3.948
	Happy	-3.506	-2.595
	Neutral	-2.420	-3.106

Figure 4-2 Nc Mean Amplitudes and Maternal Depression



Anxiety: The main effect of emotion was significant ($F_{2,132}$ = 5.69, p =.00, η_p^2=.08). Again, fearful faces elicited larger amplitudes than happy or neutral faces. The main effect of laterality was not significant ($F_{1,66}$ = .00, p =.95, η_p^2=.00). The interaction between emotion and anxiety was not significant ($F_{2,132}$ = .57, p =.57, η_p^2=.01) and the interaction between emotion, laterality and anxiety scores again, was not significant ($F_{2,132}$ = 1.31, p =.27, η_p^2=.02).

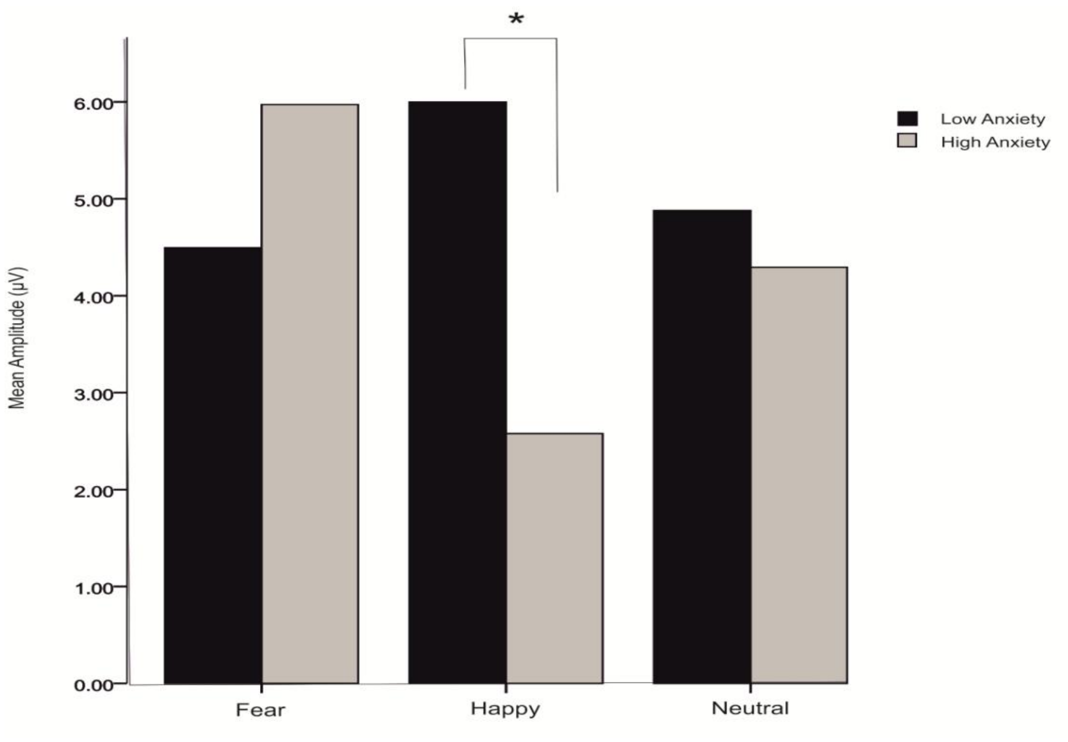
Parental Stress: The main effect of emotion was significant ($F_{2,126}$ = 7.30, p =.00, η_p^2=.10). Again, fearful faces elicited larger amplitudes than happy or neutral faces. The main effect of laterality was not significant ($F_{1,63}$ = 1.51, p =.70, η_p^2=.01). The was no significant interaction between emotion and total parenting stress scores ($F_{2,126}$ = .43, p =.65, η_p^2=.01) or between emotion, laterality and total parenting stress scores ($F_{2,126}$ = 0.67, p =.51, η_p^2=.01). The PSI subscale, *Difficult Child*, showed no significant interaction with emotion ($F_{2,126}$ =1.88, p =.16, η_p^2=.03) or laterality ($F_{1,63}$ = .08, p =.78, η_p^2=.00). Nor was there a significant interaction between emotion, laterality and the subscale *Difficult Child* ($F_{2,126}$ = .76, p =.47, η_p^2=.01). The PSI subscale *Parent-Child Dysfunctional Interaction* showed no significant interaction with emotion ($F_{2,126}$ =.58, p =.56, η_p^2=.01) or laterality ($F_{1,63}$ = .68, p =.41, η_p^2=.01). There was no significant interaction between emotion, laterality and the subscale *Parent-Child Dysfunctional Interaction* ($F_{2,126}$ =.36, p =.70, η_p^2=.01). Finally, for the PSI subscale *Parental Distress* there was no significant interaction with emotion ($F_{2,126}$ =.43, p =.66, η_p^2=.01) or laterality ($F_{1,63}$ =.66, p =.42, η_p^2=.01). Again, there was no significant interaction between emotion, laterality and the subscale *Parental Distress* ($F_{2,126}$ =1.91, p =.15, η_p^2=.03) .

4.3.2 Effects of Maternal Mental Health on the N290 ERP Component

Depression: There were no statistically significant main effect of emotion ($F_{2,134}$ =.71, *p* =.49, η_p^2=.01) or laterality ($F_{1,67}$ =.05, *p* =.83, η_p^2=.00). Nor were there a significant interactions between emotion and depression scores ($F_{2,134}$ =1.07, *p* =.35, η_p^2=.02) or emotion, laterality and depression scores ($F_{2,134}$ =.43, *p* =.65, η_p^2=.01).

Anxiety: No significant main effect of emotion ($F_{2,132}$ =.62, *p* =.54, η_p^2=.01) or laterality ($F_{1,66}$ =.02, *p* =.89, η_p^2=.00) was found at the infant N290 ERP component. However, a statistically significant interaction between anxiety and emotion was found, ($F_{2,132}$ = 4.029, *p* =.02, η_p^2=.058). Post-hoc comparisons for high and low anxiety scores were employed to tease apart this interaction. Infants of mothers with higher anxiety symptoms displayed greater negative amplitudes to happy faces (*M* = 2.6) relative to those infants' of mothers with low anxiety scores ((*M* =6.0), $F_{1,66}$ = 4.18, *p* =.05, η_p^2=.06). See Figure 4-3.

Figure 4-3 The N290, Maternal Anxiety and Emotion



* Please note that the greater negativity is shown by a smaller mean average to emotion because the average of this negative deflecting component is a positive number.

Parental Stress: There was no statistically significant main effect of emotion ($F_{2,126}$ =.48, *p* =.62, η_p^2=.01) or laterality ($F_{1,63}$ =.00, *p* =.96, η_p^2=.00). Nor were there significant interactions between emotion and total parenting stress scores ($F_{2,126}$ =.04, *p* =.96, η_p^2=.00) or emotion, laterality and total parenting stress scores ($F_{2,126}$ =.88, *p* =.42, η_p^2=.01). The PSI subscale, *Difficult Child*, showed no significant interactions with emotion ($F_{2,126}$ =.47, *p* =.63, η_p^2=.01) or laterality ($F_{1,63}$ = 2.16, *p* =.15, η_p^2=.03). Nor was there a significant interaction between emotion, laterality and the subscale *Difficult Child* ($F_{2,126}$ = 1.64 *p* =.20, η_p^2=.03). The PSI subscale *Parent-Child Dysfunctional Interaction* showed no significant interactions with emotion ($F_{2,126}$ =.09, *p* =.91, η_p^2=.00) or laterality ($F_{1,63}$ = 2.91, *p* =.09, η_p^2=.04). There was no significant interaction between emotion, laterality and the subscale *Parent-Child Dysfunctional Interaction* ($F_{2,126}$ =2.95, *p* =.06, η_p^2=.05). Finally, for the PSI subscale *Parental Distress* there was no significant interactions with emotion ($F_{2,126}$ =1.84, *p* =.16, η_p^2=.03) or laterality ($F_{1,63}$ =.07, *p* =.80, η_p^2=.00). Again, there was no significant interaction between emotion, laterality and the subscale *Parental Distress* ($F_{2,126}$ =.13, *p* =.88, η_p^2=.00) .

4.3.3 Effects of Maternal Mental Health on the P400 ERP Component

Depression: There were no statistically significant main effect of emotion ($F_{2,134}$ =1.27, *p* =.28, η_p^2=.02) or laterality ($F_{1,67}$ =171, *p* =.98, η_p^2=.00). Nor were there significant interactions between emotion and depression scores ($F_{2,134}$ =.22, *p* =.80, η_p^2=.00) or emotion, laterality and depression scores ($F_{2,134}$ =.13, *p* =.88, η_p^2=.00).

Anxiety: There was no statistically significant main effect of emotion ($F_{2,132}$ = 1.40, *p* =.26, η_p^2=.02) or laterality ($F_{1,66}$ = .31, *p* =.17, η_p^2=.03). The interaction between emotion and anxiety was not significant ($F_{2,132}$ =1.82, *p* =.17, η_p^2=.01) and the interaction between emotion, laterality and anxiety scores again was not significant ($F_{2,132}$ = .51, *p* =.60, η_p^2=.01).

Parental Stress: There was no statistically significant main effect of emotion ($F_{2,126}$ =1.58, *p* =.21, η_p^2=.02) or laterality ($F_{1,63}$ =.17, *p* =.76, η_p^2=.00). Nor were there significant interactions between emotion and total parenting stress scores ($F_{2,126}$ =.95, *p* =.39, η_p^2=.02) or emotion, laterality and total parenting stress scores ($F_{2,126}$ =.68, *p* =.51, η_p^2=.01). The PSI subscale, *Difficult Child*, showed no significant interactions with emotion ($F_{2,126}$ =1.67, *p* =.20, η_p^2=.03) or laterality ($F_{1,63}$ = .95, *p* =.34, η_p^2=.02). Nor was there a significant interaction between emotion, laterality and the subscale *Difficult Child* ($F_{2,126}$ = 1.39 *p* =.25, η_p^2=.02). The PSI subscale *Parent-Child Dysfunctional Interaction* showed no significant interactions with emotion ($F_{2,126}$ =.03, *p* =.97, η_p^2=.00) or laterality ($F_{1,63}$ = 1.12, *p* =.30, η_p^2=.02). There was no significant interaction between emotion, laterality and the subscale *Parent-Child Dysfunctional Interaction* ($F_{2,126}$ =.96, *p* =.39, η_p^2=.02). Finally, for the PSI subscale *Parental Distress* there was no significant interactions with emotion ($F_{2,126}$ =.04, *p* =.10, η_p^2=.00) or laterality ($F_{1,63}$ =.06, *p* =.81, η_p^2=.00). Again, there was no significant interaction between emotion, laterality and the subscale *Parental Distress* ($F_{2,126}$ =.59, *p* =.55, η_p^2=.01) .

4.4 Discussion:

The impact of maternal mental health on a child’s social and emotional development is a central topic in the field developmental psychopathology. Observational studies, and more recently, neuroscientific research indicates that disruptions within the parent-infant relationship, as a result of enduring parental mental health difficulties, impacts on a range of developmental outcomes (Cummings & Davies, 1994; Goodman & Gotlib, 1999; Goodman, et al., 2011; Lupien, et al., 2011;

Murray & Cooper, 1997). Together, this research has provided the foundations for understanding the long term effects of parental mental health on later child social and emotional outcomes. What is less clear in the literature is the impact that maternal mental health difficulties has on offspring neural processing in early development, particularly relevant to emotional development, and little research has examined whether mental health symptoms in normative samples are associated with infant neurocognitive development. This investigation aimed to address this gap in the current literature. Overall, the results from this investigation provided some positive evidence that maternal metal health in non-clinical samples is associated with offspring neural responses to emotions in infancy. Specifically, low levels of maternal depressive symptoms were associated with greater (more negative) infant ERP amplitudes at the Nc to positive and neutral emotion, while high levels of maternal anxiety were related to larger (more negative) electrical amplitudes at the early infant face sensitive ERP component the N290, again to positive emotion. As such, the results in part confirmed this study's first hypothesis that infants of anxious mothers will show a neural sensitivity to *positive emotion* at the early-appearing face sensitive component, the N290. The current study failed to provide evidence for the second hypothesis, that infants in a low-risk community sample who have parents with relatively elevated mental health symptoms, would show an increased sensitivity to *negative emotion* at the later face and emotion sensitive component the Nc and P400.

4.4.1 Maternal Depression and Infants' Neural Processing of Emotion

The findings from this study suggest that infants whose parents reported low levels of depressive symptoms have increased (negative) amplitudes to positive emotional expressions over the left hemisphere and increased (negative) amplitudes to neutral emotional expressions over the right hemisphere for the infant emotion sensitive Nc ERP component, compared to infants who have parents who reported high levels of depression. Increased neural activity on the Nc has often been related to an increase in attentional resources (Ackles & Cook, 1998; Nelson & De Haan, 1996; Richards, 2003; Vaughan Jr & Kurtzberg, 1992) and is thought to reflect the saliency of the stimuli (De Haan, et al., 2003; Karrer & Ackles, 1987; Nelson & De Haan, 1997). Considering positive emotion first, a plausible explanation of this finding is that an infant whose mother is low in depressive symptoms is more likely to experience an interaction that is characterized with positive and warm affect. This is highly likely given that infants who experience a parent with high depressive symptoms are more likely to be exposed to insensitive caregiving (Goodman & Brumley, 1990; Lovejoy, et al., 2000). Greater exposure to positive emotions may lead the infant to encode positive emotion as more salient and thus is represented by increased negative neural amplitudes at the Nc ERP component. It may be that infants who are exposed to higher displays of positive affect experience these emotion displays as rewarding, which in turn promotes heightened attention. Positive expressed emotions are more likely to be accompanied by warm social interactions (Darling & Steinberg, 1993; Zhou, et al., 2002) and as such, these emotions become highly salient as the infant is able to associate this emotion with a social reward. For infants of parents with higher levels of depression, there may be fewer opportunities to learn about positive emotional signals and/or they may be less consistently associated with rewarding social interaction. The prevalence of incongruent affect displays amongst mothers with depression is notable (Tronick & Reck, 2009) and may also contribute to the infant’s failure to encode positive emotional expressions as rewarding. This would be true for both intrusive and withdrawn depressed parental styles. There is, of course, the possibility that these infants of parents with low depressive symptoms are in fact more familiar with positive emotional expressions and as such, the increase in neural amplitudes at the Nc is in fact reflective of the infants familiarity with this emotion. Given that the Nc has been shown to be sensitive to familiar stimuli (De Haan & Nelson, 1997, 1999; Nelson et al., 2000), this is highly probable. Further investigations looking at actual exposure to specific expressed emotion during parent-infant interactions would be crucial to substantiate this point. It is important to note that this finding was specific to the left hemisphere only and as such can be seen to provide additional support to the evidence that suggests left hemisphere activity is related to the processing of positive emotion and approach behaviour in non clinical populations (Fox, 1991).

The second significant finding related to maternal depression showed that infants of mothers with low depressive symptoms had significantly greater (more negative) amplitudes to neutral facial expressions over the right hemisphere compared to those infants of mothers with high depressive symptoms at the infant Nc ERP component. This finding would seem to suggest that for infants of parents reporting low depressive symptoms, neutral faces are salient and require more neural effort to process. There is some evidence that suggests neutral facial expressions are in fact not neutral and void of emotion but are rather processed as negative (Lee, Kang, Park, Kim, & An, 2008). Given that our result was specific to the right hemisphere, which has a well documented relationship with negative emotion (Davidson, 1995; Fox, 1994a), it is interesting to hypothesize that infants of mothers with low depressive symptoms could be processing neutral faces in a similar way to processing negative emotion. However, this relationship has only been established on frontal EEG activation in the alpha frequency range rather than ERPs, so some caution is necessary. Furthermore, it is also highly plausible that these infants are rarely exposed to a sudden neutral and unresponsive face during face-to-face interactions and as such, when exposed to a neutral face, greater attention is required to understand the sudden lack of affect. There is, of course, substantial evidence to indicate that infants of mothers with high depressive symptoms experience more disengaged parenting during day-to-day interactions with their mother (for a review see Lovejoy, et al., 2000) and as such, experiencing a neutral face for these infants does not violate their social expectations. This interpretation would result in their requiring less neural attention to process a neutral face. This is plausible given the substantial amount of empirical evidence indicating typical infants' increased behavioural response to a neutral and unresponsive face (the still-face effect; for a review see Mesman, van IJzendoorn, & Bakermans-Kranenburg, 2009) and the reduction in that same behavioural response during a still-face procedure for infants of depressed mothers (Field, Hernandez-Reif, et al., 2007; Nadel, Soussignan, Canet, Libert, & Gérardin, 2005). Clearly the methodological differences between the still-face paradigm and a passive face-viewing task, as employed in this study, make direct comparisons difficult but useful parallels can be drawn.

4.4.2 Maternal Anxiety and Infant Neural Processing of Emotion

In regards to maternal anxiety, the results of this study suggest that infants neural processing of emotional faces is related to varying levels of maternal anxiety. In particular, parental levels of anxiety were associated with altered EEG amplitudes on the infant face sensitive ERP component the N290. Specifically, infants whose mothers reported high levels of anxiety symptoms had increased neural responses to happy emotional expressions on the N290 ERP component.

The commonly accepted interpretation of the function of the infant N290 is that it primarily reflects structural encoding of face stimuli and is reflective of processes similar to the adult face sensitive ERP component the N170 (De Haan, et al., 2002; Halit, et al., 2004; Halit, et al., 2003). In particular, differences in amplitudes to the N290 have been associated with human face stimuli recognition (De Haan, et al., 2002). The results from this study are particularly intriguing in regards to encoding positive emotion as it provides additional evidence, at a neural level, to the behavioural data that shows infants of parents with mental health difficulties display a preference to look at and take longer to habituate to positive emotion (Bornstein, et al., 2011; Hernandez-Reif, Field, Diego, Vera, et al., 2006). In this regard, it could be argued that these infants who experience mothers with high levels of anxiety are exposed less to positive emotion, resulting in their infants requiring more neural effort to encode this unfamiliar face. This is highly likely given the evidence that suggests anxious parents display less warm and positive affect while interacting with their child (Budinger, Drazdowski, & Ginsburg, 2013). Furthermore, this study is not the first to report a novelty affect at the infant N290 ERP component. Righi and colleagues (2014) found that infants who were familiarised to one female face displayed an increase in neural amplitudes at the N290 when presented with an unfamiliar female face. However, it is important to note that in the same study, Righi and colleagues reported that infants also displayed increased amplitudes at the N290 for all female faces compared to male faces. It was argued by the authors that this neural sensitivity to female faces is due to the fact that a female face is more familiar to the majority of infants – a type of perceptual expertise. In light of this and another study that found the N290 to be sensitive to familiarity (Scott, et al., 2006), one could equally argue that infants of mothers with high anxiety levels are sensitive to social signals such as smiles as a result of their anxious mothers possibly smiling more at them. This is a plausible given that there is some, although limited, evidence that suggests anxious individuals display non-genuine happiness, including polite smiles (as opposed to pleasant/genuine smiles) and nervous laughter (Harrigan & Taing, 1997; Heerey & Kring, 2007). Again, further investigations into infants' precise exposure to facial displays of affect would be extremely beneficial.

Finally, a recent adult study by Morel and colleagues (2014) found that early ERP responses on the P1component were larger for happy faces for those adults experiencing trait anxiety symptoms compared to fearful and neutral emotional faces. This adult finding combined with this infant investigation provides valuable support for an early neural sensitivity in encoding positive emotional expressions in relation to experienced anxiety.

4.4.3 Parental Stress and Infant Neural Processing of Emotion

Parental stress was the third domain of parental mental health wellbeing examined in this study. This is a plausible candidate to investigate because research has shown that high levels of parental stress may adversely affect parenting behaviour, which in turn may impact on the child's emotional development (Anthony, et al., 2005; Cappa, et al., 2011; Denham & Grout, 1993; Denham, et al., 1994; Neece, et al., 2012). However, our findings did not provide strong evidence that parental stress is associated with differences in infant neural processing of emotions. Overall, parental stress was not associated with any of the three ERP components related to emotional face processing. The main reason for this lack of association may be due to the range of parental stress recorded. Only 4.2% of this sample qualified in terms of clinical caseness in regards to parental stress, as opposed to 39.1% for depressive symptoms and 57.4% for anxiety. This lack of variation in reported parental stress levels may have contributed to this null finding.

4.5 Limitations

There are some limitations to the current study. Firstly, the sample used was restricted to a relatively advantaged, middle class population. Although normative in theory, this sample is by no means representative of a typical western population. For example, 83% of this sample has an education level of undergraduate degree or above. This, compared to the national UK average of 38%, highlights the discrepancies between our sample and a more normative population (Office for National Statistics, 2013). As such, the findings from this research may not generalise to other populations. Future research incorporating a more diverse normative sample would be beneficial. Secondly, although parent-report questionnaires measuring maternal mental health provide a useful insight into the possible environment an infant may be experiencing, they are nonetheless vulnerable to bias. The maternal mental health measures selected for this study were well validated and reliable instruments. However, they do not directly address parent-infant interaction, which is hypothesized to be the mechanism by which maternal mental health affects infant brain development. With this particular study, the employment of emotional face stimuli to assess neural differences in emotional development is a strength in that these are well controlled stimuli that have been studied extensively in the past. However, a focus on facial emotional expressions raises questions about the amount and level of exposure each infant has to emotional faces in the home, and our lack of data regarding this means that we cannot determine how much of an impact such variation might have had on our findings. As such, future research would benefit from examining the exposure an infant has to specific facial expressions through assessing mother-infant interactions more closely. A closer inspection of parental interactions styles would tease apart the subtleties of an infant's exposure to particular emotional expressions and highlight the associated neurological differences. Finally, maternal mental health, although important, is only one part of the infants' social experience. Future studies that look at other areas of the parent-infant relationship in relation to infants processing of emotion would prove useful.

4.6 Conclusions and Summary

In conclusion, this chapter suggests that emotional face processing in infancy can be influenced by individual experience. In particular, variations in levels of maternal mental health were associated with altered neural responses to emotional faces in their offspring. The evidence found in this investigation suggests that maternal anxiety is associated with their infants processing of positive emotion at the early face-sensitive N290 ERP component. A possible novelty effect may be responsible for increased neural activity to positive emotion for infants with parents who report high levels of anxiety symptoms at the N290 as the result of more structural encoding of unfamiliar or less experienced emotional expressions. Heightened neural activation on the later Nc ERP component was evident for both positive and neutral emotional faces, for infants with parents experiencing low levels of depression. Overall, this study highlights the plasticity of the neural pathways involved in processing emotion in relation to environmental factors, particularly maternal mental health. Given this understanding, the need to identify early indicators of maternal mental health problems is paramount. First and foremost, the data presented in this chapter highlights that an infant's neural processing of emotion, primarily positive emotion, is subject to alteration in relation to varying degrees of maternal mental health and this can be indexed as young as 7 months of age. Although it is not possible to reliably predict the downstream effects of these early neural differences, the data highlights the need to promote screening processes to help identify those at risk for developing mental health problems as early as possible. Furthermore, the data presented may provide useful ways of focusing early interventions for parents experiencing mental health difficulties by specifically approaching expressed emotional communication within the dyad, perhaps with a particular emphasis on the importance of promoting positive emotional experiences. Finally, given our understanding of the plasticity of these neural pathways in relation to emotion processing for these infants, there is a need to provide parents who are experiencing mental health difficulties with a network of social support that can potentially support healthy neural development in infants at times when a parent is unable to provide this.

4.7 Key Findings:

- Neural processing of emotion in 7 month old infants is related to varying levels of maternal mental health.
- Low levels of maternal depression are associated with increased amplitudes to happy emotional faces over the left hemisphere at the infant Nc ERP component.
- Low levels of maternal depression are associated with increased amplitudes to neutral emotional faces over the right hemisphere at the infant Nc ERP component.
- High levels of maternal anxiety are associated with increased amplitudes to happy emotional faces on the infant N290 ERP component.

5 Parenting and Infants' Neural Responses to Emotion

This chapter has been peer reviewed in Child Development (Taylor-Colls & Fearon, 2015)

The evidence put forward is chapter 4 highlights how the early shared environment between mother and infant can relate to the neurological mechanisms deemed relevant in emotion processing. Assessing maternal mental health is a useful way of understanding the type of parent an infant may experience however it is not a direct observation of parenting behaviour. Chapter 4 focused on self-report measures to assesses maternal mental health and although this is clearly a quick and cost-effective way of assessing the early environment it is by no means without it methodological limitations. As such, chapter 5 focuses on direct observations of parenting behaviour through independently coded free-play interactions in relation to infants' EEG responses to emotional facial expressions. By incorporating direct observations to assess parental interactive behaviour, chapter 5 aims to advance our understanding of the early parent-infant relationship beyond that of current maternal mental health status to assess whether parenting behaviour in typical developing relationships may directly influence infants' neurological processes.

5.1 Introduction:

There is a great deal of current scientific interest in the impact of early experience on brain development (for a review see Belsky & De Haan, 2011). Studies of extreme deprivation occurring during childhood, such as maltreatment or institutional rearing, have yielded consistent evidence demonstrating a range of effects on several structural and functional brain parameters. For example, there is evidence to suggest that institutionally reared children have larger amygdala volumes compared to family-reared children (Mehta, et al., 2009), with the length of stay in institutions also accounting for variation in amygdala volumes within this group (Tottenham, et al., 2010). Further, research has indicated that past maltreatment is associated with reduced hippocampal volume in adults, and that children exposed to maltreatment show reduced corpus callosal volume (for a review see McCrory, et al., 2012). Furthermore, several studies have shown that maltreated children, relative to controls, display increased neural responsivity to angry facial expressions, as well as parallel biases in attention to, and categorization of, angry faces (Pollak & Kistler, 2002; Pollak, et al., 2001; Shackman, et al., 2007). While these studies are of exceptional importance for understanding the impact of extreme deprivation, and represent proof-of-principle that early environments can be shown to influence brain function, they do not shed light directly on whether and how the vast majority of variability in parental care occurring outside these extremes influences brain development. This is of vital importance because the quality of early parental care, particularly the extent to which that care is sensitive and responsive to the infant's cues and communications, is known to be a very important influence on long-term social and emotional development (Belsky & Fearon, 2002; Kertz, et al., 2008; Mäntymaa, et al., 2004; NICHD Early Child Care Research Network, 1999; Sroufe, 2005; Zhou, et al., 2002).

Faces are exceptionally important signals for infants to detect and learn about in the first year of life, and past research has demonstrated that infants possess early-appearing and rapidly developing abilities to do so. For example, infants preferentially orient to face-like stimuli at birth (Fantz, 1963; Goren, Sarty, & Wu, 1975; Johnson, Dziurawiec, Ellis, & Morton, 1991; Maurer & Young, 1983; Pascalis, de Schonen, Morton, Deruelle, & Fabre-Grenet, 1995; Simion, Valenza, Umilta, & Barba, 1998; Stechler, 1964; Valenza, Simion, Cassia, & Umiltà, 1996) and recognize their mother's face within the first few days of life (Pascalis & de Schonen, 1994). Clear evidence that infants distinguish emotional expressions in face stimuli can been found between 5-7 months of age (De Haan, et al., 2003; Nelson, 1987; Peltola, et al., 2009). As a pre-verbal infant, a primary means of communicating with the world is through reading others' emotional expressions, in particular the parents (Klinnert, 1984). It is through this interaction with a primary caregiver that an infant begins to learn about the vital social signals necessary for interacting with and understanding the behaviours of others (Denham, et al., 2002; Greig & Howe, 2001; Laible & Thompson, 1998; Ontai & Thompson, 2002; Raikes & Thompson, 2006; Rosnay & Harris, 2002; Steele, et al., 1999). This ability is not only fundamental for an infant to interpret others' feelings and intentions but also allows them to derive information about the world around them, for example what is safe or not (Sorce, Emde, Campos, & Klinnert, 1985). This evolving understanding of socialisation allows the infant to predict others' behaviours, and as a result guides the infants' reciprocal behaviour, including their ability to regulate their own emotional responses (Fox, 1994b).

This impressively early socio-cognitive ability can be argued as one of the fundamental processes from which greater social understanding emerges. There is now strong evidence that suggests that those who have an inability to recognise and discriminate facial displays of affect are more likely to experience mental health problems. This is evident in both children (Blair, 2006; Marsh & Blair, 2008; Sinzig, Morsch, & Lehmkuhl, 2008) and adults (Blair, 2006; Dolan & Fullam, 2006; Norton, McBain, Holt, Ongur, & Chen, 2009). Therefore, considering the early emergence of an infant's emotion processing ability and the potentially important role that parental behaviour has in its development, it becomes of great importance and urgency to understand how variations in parenting behaviour may impact on this vital neurological process.

There are two lines of evidence that motivate the expectation that neural systems subserving emotion processing in early life may be affected by variation in parental care outside of frank abuse or severe privation. First, there is now substantial evidence that infants of depressed mothers show greater relative right frontal EEG activation in the alpha frequency range than infants of non-depressed mothers (Dawson, et al., 1999;

Dawson, et al., 1992; Field, 1995; Jones, et al., 2009; Jones, Field, Davalos, et al., 1997; Jones, Field, Fox, et al., 1997). This hemispheric EEG bias appears to be associated with differences in emotion, particularly negative affect and withdrawal, both in adults and children (Davidson, 1995; Fox, 1994a). Although one cannot conclude with certainty that asymmetries in alpha activation are linked to neural processes specifically linked to the processing of emotions (such as facial expression), Davidson & Fox (1982) found that infants show transient EEG shifts towards greater relative right activation when processing negative emotion-expressions. Furthermore, this same stimulus-linked asymmetry appears to be enhanced in infants of depressed mothers when observing negative emotional faces compared to positive emotional faces (Diego, et al., 2002). A recent study provides more direct evidence of differential facial emotion processing in infants related to maternal depression (Forssman, et al., 2014). The results of this behavioural study indicated that maternal depressive symptoms were associated with infants' decreased attentional disengagement from fearful facial expressions relative to happy or neutral expressions, as measured using eye tracking (Forssman, et al., 2014). Finally, a recent structural imaging study of 10-year olds found that maternal depressive symptoms experienced across childhood were associated with larger amygdala volumes, a brain region closely involved in emotional information-processing (Lupien, et al., 2011; though see alsoMoutsiana, et al., 2014).

In addition, the evidence presented in this thesis in chapter 4 is suggestive of a relationship between maternal mental health in particular, varying degrees of depression and anxiety, and infants' ERP responses to expressed emotion. While it is not possible to rule out the possibility that other factors might be involved, particularly genetically-influenced affective tendencies shared by mother and child, a disturbed pattern of parent-child interaction is a plausible explanation for these differences in emotion-related neural activity, attentional disengagement and possibly even brain structure, in the offspring of mothers with depressive disorder or depressive symptoms. Consistent with the assertion that parental behaviour may play a key role, Hane and Fox (2006) found that directly observed parenting insensitivity was associated with greater relative right frontal EEG asymmetry in 9-month old infants. This study arguably provides the strongest current evidence of parenting effects on infant brain function.

Thus, there is convergent evidence that maternal depression may be associated with changes in young children's processing of emotion, and there is good indirect evidence that this may be linked to disturbances in parent-child interactions. Furthermore, postnatal depression appears to be associated with a *sensitization* of neural systems linked to negative emotion in particular, although whether, and indeed which, parenting processes are responsible for this sensitization remains to be thoroughly explored. Given that the features of parenting that are affected by postnatal depression – particularly hostile, intrusive and/or withdrawn parenting – are by no means restricted to it, it is plausible to expect that variation in parenting in non-depressed samples would be associated with measurable differences in infant neural correlates of emotion processing, although to date no study has directly tested this.

A second source of evidence comes from a study by De Haan and colleagues (2004) who examined the relationship between maternal personality and infant ERP responses to emotional faces. These authors chose maternal personality as an indirect marker for the infant's exposure to different patterns of parental care in light of the extensive evidence that personality influences parenting (L. Clark, Kochanska, & Ready, 2000; Spinath & O'Connor, 2003). De Haan et al. found that infants of mothers who were high on positive affect showed greater Nc amplitudes in response to negative, relative to positive, emotion expressions, although only when the infant also scored highly on a dimension of temperamental positive affect. Looking-time data also indicated that infants of mothers who scored highly on positive affect also tended to show shorter looking times to positive emotional expressions. Given these findings, De Haan et al. interpreted their results to indicate that, in contrast to the sensitization effects described above for postnatal depression, maternal positive affect may lead to a diminished neural response to happy facial expressions, through repeated exposure within the caregiving environment. The findings are intriguing, although limited by their lack of direct observation of parenting.

In the current study we tested the association between directly observed parenting behaviour and infant neural processing of emotion in a sample of 40 7-month old infants. We predicted that event-related potentials related to facial emotion processing would be linked to variations in the quality of parental care. Consistent with previous chapters this investigation focused on the three most studied infant ERP components, the Nc, the P400 and the N290. When measuring parenting, we examined maternal sensitivity and responsiveness in particular, because of their central importance to models of early child development (e.g., attachment theory) and their robust empirical association with a wide range of developmental outcomes. Because there is evidence for both sensitization and habituation/exposure effects of parenting on infant emotion processing, we did not advance strong directional hypotheses. Finally, in light of De Haan et al.'s (2004) findings we explored possible interactions between parental sensitivity and infant temperament in infants' neural responses to emotional faces.

5.2 Methods

5.2.1 Participants

Mothers and their healthy seven-month-old infants were recruited from a database of community volunteers who agreed to be contacted for developmental studies (please see chapter 2). Seventy-seven 7-month-old infants (mean age = 229 days, 40 males and 37 females) and their mothers participated in this study. All infants were born full term (i.e., 37-42 weeks) and of normal birth weight. Of the 77 infants who participated, 40 (mean age = 230 days, *SD*= 9.8, 17 females) had usable EEG data. The remaining thirty seven infants were excluded due to fussiness/inattentiveness and excessive ERP artefact including eye and body movement. As seen in previous chapters this attrition rate is not only consistent with other infant ERP studies but is clearly not a threat to the validity of this study (De Haan, et al., 2004; Leppänen, et al., 2007). Notably, the infants who were excluded did not significantly differ from those who were included in terms of temperament, child gender, maternal age, family household income, maternal occupation or maternal education (lowest p-value = .24). The inclusion criteria for this study required infants to have good EEG data on at least ten trials per emotional face viewing condition to qualify for further data analysis. The study was approved by University College London's Research Ethics Committee.

Table 5-1 Sample Description

Sample Description **N = 40**	
Mother age in years:	
Mean (SD)	34.9 (4.8)
Range	20.8 - 50.5
Child age in months:	
Mean (SD)	7.7 (0.3)

Range	7.2 - 8.2
Child gender: N (%)	
Female	17 (43%)
Male	23 (57%)
Number of other children: N (%)	
First time mothers	32 (80%)
More than one child	7 (17%)
Missing	1(3%)
Mother ethnicity: N (%)	
White	31 (77.5%)
Black	1 (2.5%)
Asian	2 (5%)
Mixed	1(2.5%)
Other	1 (2.5%)
Missing	4 (10%)
Mothers' education N (%)	
Secondary School	1 (2.5%)

Further Education	1 (2.5%)
Higher Education	33 (82.5%)
Missing	5 (12.5%)
Mothers' Employment N (%)	
Employment	31 (77.5%)
Unemployment	4 (10%)
Missing	5 (12.5%)
Household Income N(%)	
Below £30,000 per year	3 (7.5%)
Above £30,000 per year	29 (72.5%)
Missing	8 (20%)

5.2.2 Procedure

As explained in previous chapters, parents who agreed to take part in the study visited the laboratory when their infants were 7 months old. Parents were provided with a written and verbal description of the full experimental procedure and gave written informed consent from the parent. Infants first took part in the EEG recording with the procedure being identical to previous chapters, on average the EEG recording lasted about 20 minutes including net application and a recording of 3 minutes of resting data. Infants were securely and comfortably sat in an infant car seat in a soundproof room at a viewing distant of 50cm from a 10.5 inches x 13.5 inches screen. The experiment consisted of one block of 210 face trials (70 Happy, 70 Fearful and 70 neutral). Each trial was shown for a duration of 500 milliseconds and was presented in a random order. The inter-stimulus interval varied randomly between 500 and 1000ms. Trials began once the infant's attention was drawn to the screen. The infant's behaviour was monitored by a researcher through a video camera in the next room. If the infant became fussy the researcher activated a bright colourful animation with sound to redirect the infant's attention to the screen. When an infant's attention could no longer be redirected to the monitor, the session was terminated. Parents were instructed to not interact with their infant at all during the session, and were told that if their infant turned to look at them they were to avoid eye contact and look straight ahead. After a short break, mothers and their infants were then videotaped while playing together in our purpose built baby-friendly room. Mothers were instructed to play with their infant as they usually would at home. The first 3 minutes of recording included a free play interaction without toys followed by a further three minute free play interaction with toys.

5.2.3 Emotion Stimuli

Again, as previously described the stimuli consisted of 5 female actors each posing a happy, neutral or fearful face (210 total trials). The faces were posed against a white background and were cropped so no hair or other features could be seen. The static images were centrally positioned and measured 12cm x 9cm on a 10.5 inches x 13.5 inches on the screen. The stimuli were provided by the MacBrain Face Stimulus Set. Development of the MacBrain Face Stimulus Set was overseen by Nim Tottenham and supported by the John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development.

5.2.4 EEG recording

EEG was recorded continuously during the face viewing trials using a 128 hydrocel geodesic net (Electrical Geodesic Inc. Eugene, OR) referenced to the vertex (Cz). The electrical signal was amplified with a 0.1-to 100-Hz band-pass with a sampling rate of 250Hz. All EEG data were analysed offline using the EEG platform EEGLAB (Delorme & Makeig, 2004), and in-house custom made MATLAB scripts.

5.2.5 Data reduction

The data reduction technique is the same as described in previous chapters. For each participant the EEG signal was segmented into an epoch ranging from 100ms before stimulus onset and extending to 750ms after stimulus onset. Before any EEG data was analysed, the video recording of the infant was examined thoroughly and segments were rejected when the infant was not looking at the screen. The remaining digitally filtered (0.1Hz-30Hz) and baseline corrected segments were visually inspected for artefacts relating to movement or high frequency noise. Bad channels were identified and replaced using spherical spline interpolation. Segments that displayed large artefact or high frequency noise were removed from further analysis. Independents component analysis was run using FASTER to remove stereotyped artefacts (Nolan, et al., 2010). Finally, with a minimum of 10 trials per experimental condition, the data was averaged and re-referenced to the average reference. The average number of good trials was 21 (SD = 8.2, range = 10 – 48) for fearful faces, 22 (SD=8.7, range=10 - 45) for happy faces and 20 (SD=7.1, range =10- 43) for neutral faces.

5.2.6 Parenting

The parent-infant interactions were later coded using the Emotional Availability Scales (EA; Z. Biringen, 2000; Z Biringen, Robinson, & Emde, 1993; Zeynep Biringen, Robinson, & Emde, 2000). The EA is a measure that draws heavily on attachment theory, with the emphasis being on the contribution of both the parent and infant on the evolving interaction. The EA scales are comprised of four parental dimensions: 1) Sensitivity, measured on a 9-point scale, *2)* Structuring, on a 5-point scale, 3) Non-intrusiveness, on 5-point scale and 4) Non-hostility, on a 5-point scale. The EA scales have been shown to robustly predict infant attachment classifications (Easterbrooks, Lyons-Ruth, Biesecker, & Carper, 1996; Koren-Karie, Oppenheim, Dolev, Sher, & Etzion-Carasso, 2002; Ziv, Aviezer, Gini, Sagi, & Karie, 2000) and have been demonstrated to be stable over time from 6 to 12, to 20 months of age (Ziv, Gini, Guttman, & Sagi, 1997). The four scales were strongly inter-correlated (rs ranging from .37 to .55). In order to reduce the number of variables for analysis and create a more reliable overall index of sensitivity, the 4 scales were standardized and summed (Cronbach's alpha = .77). The interactions were coded by a single coder who was blind to the EEG data. Independent reliability coding of 25% of the data showed acceptable reliability (individual scale reliability coefficients were *ICC* = .71 –.75, overall composite scale *ICC* = .80).

5.2.7 Infant Temperament

Due to the possible role that temperament may play in the processing of emotional faces (De Haan, et al., 2004) and the influential relationship it has to parental caregiving (Campbell, 1979; Crockenberg & Acredolo, 1983; Kelly, 1976; Kyrios & Prior, 1990; Linn & Horowitz, 1983; Paulussen-Hoogeboom, Stams, Hermanns, & Peetsma, 2007) we included the data on infant temperament from the Infant Behaviour Questionnaire (IBQ; see Rothbart, 1981). As previously addressed in chapter 3, the IBQ assesses the frequency of specific temperamental behaviours that have been observed in the last week and results in six temperamental dimensions: activity level, smiling and laughing, distress, and latency to approach sudden or novel stimuli distress to limitations, soothability and duration of orienting. In this study, we were interested in indices related to negative and positive affect, and hence we selected the following scales: distress and latency to approach, distress to limitations, soothability, and smiling and laughter. The two distress scales correlated quite highly (r = .51) and were therefore standardized and summed to create a “distress” index. As previously mentioned in chapter 3, high internal consistency across all six dimensions has been demonstrated at 3, 6, 9, and 12 months of age for the IBQ (Rothbart, 1981).

5.2.8 Statistical Analysis:

Consistent with the previous chapters in this thesis, the following same three infant ERP components were selected the Negative Central (Nc), the P400 and the N290. Time windows for all three infant ERP components, were again selected by examining the grand average waveform for all participants in this study (the smaller sample N=40) and looking at past studies’ selected time windows.

Negative Central (Nc): The central electrode cluster is the same as previous chapters; left: 35, 41, 36, 47, 42 and right: 110, 104, 103, 93, 98. The time window for the Nc begin at 350ms after stimulus onset and extends to 650ms after stimulus onset.

N290 and P400: The electrode cluster for both ERP components is the same as previous chapters; left: 66, 70, 65, 69, 64 and right: 84, 83, 90, 95, 89. The time window for the P400 was again 350ms after stimulus onset and extends to 600ms after stimulus onset. The N290 begins at 250ms after stimulus onset and ends at 350ms after stimulus onset.

5.2.9 Data Analysis

The analysis of Nc amplitude involved the use of mixed 2 (hemisphere, left vs. right) × 3 (emotion, fear, happy, neutral) analyses of variance, with sensitivity or temperament entered as continuous covariates. Correlational and regression analyses were used to follow up any sensitivity or temperament effects, based on a subtraction of average Nc amplitudes for emotional faces from neutral faces (fear–neutral; happy–neutral). We chose this contrast because our main hypotheses focused on neural responding to emotion, and hence the neutral/nonemotional face stimuli represented the most pertinent point of reference. Interactions between temperament and sensitivity were tested using regression, in which interactions were computed as the product of the linear effects of each variable (Temperament × Sensitivity).

5.3 Results

5.3.1 Effects of Emotion, Laterality and Sensitivity on Nc Amplitude

The main effect of emotion was statistically significant, indicating that mean Nc amplitudes differed according to the emotion of the face stimuli ($F_{2,76}$ = 3.55, *p* = .034, η_p^2=.085). Consistent with previous findings, fearful faces elicited larger amplitudes (*M* = -4.78) than Happy (*M* = -3.73) and neutral (*M* = -3.50) faces (see figure 5.1). The main effect of Laterality ($F_{1,38}$ = 1.30, *p* = .26, η_p^2=.033) was not significant. However, there was a significant Emotion x Sensitivity interaction ($F_{2,76}$ = 3.39, *p* = .039, η_p^2=.082). To tease apart this interaction, we created two difference scores reflecting the amplitude of each emotional face relative to neutral faces (Fear - Neutral, Happy - Neutral) and correlated each of these with sensitivity. The relative Nc amplitude for fearful faces did not correlate with sensitivity (*r* = -.071, *p* = .67), but the relative Nc amplitude for happy faces did (*r* = -.41, *p* = .008). In other words, higher maternal sensitivity was associated with a larger, more negative, Nc for happy faces relative to neutral faces. A scatterplot showing this association is presented in Figure 5.2. Notably, this correlation was maintained after controlling for gender (*r* = - 41, *p* =.009).

Figure 5-1 Nc Waveform (Nc time window shaded in grey)

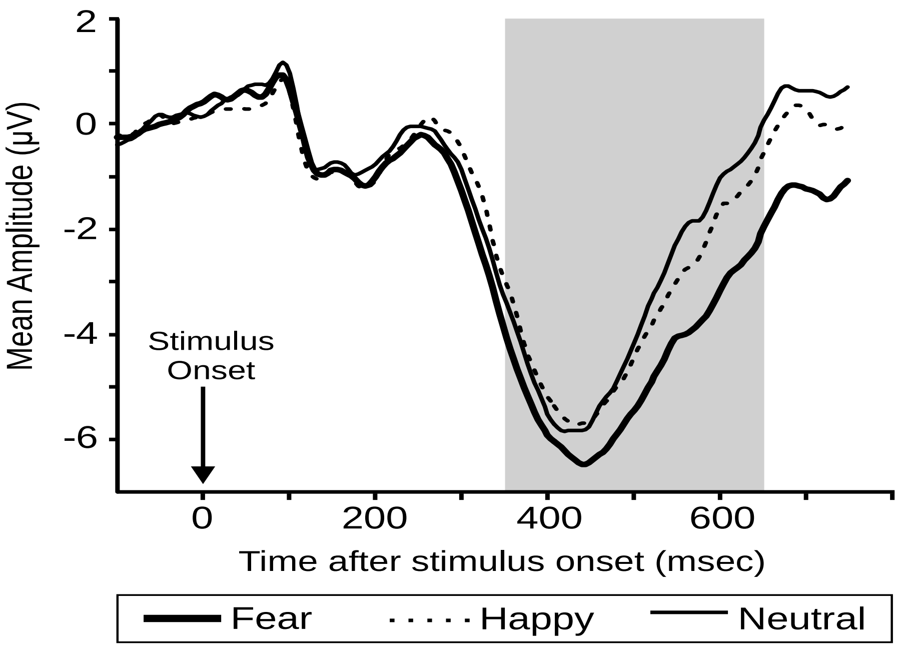
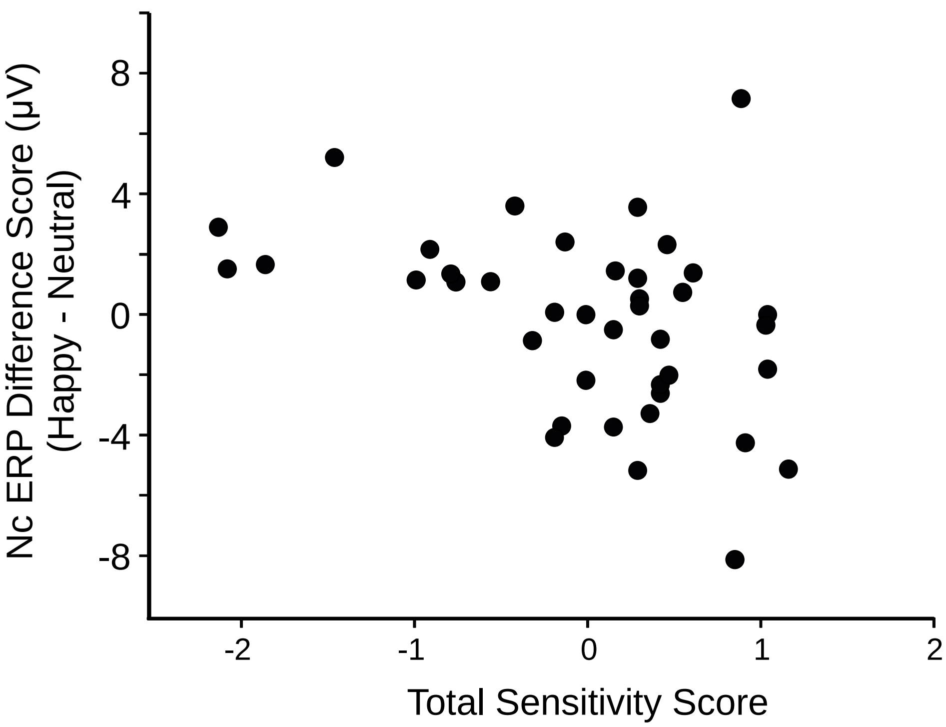


Figure 5-2 Scatterplot of happy minus neutral Nc amplitude and maternal sensitivity



5.3.1 Temperament Effects

Consistent with the results reported in chapter 3, when we examined the average Nc amplitude in relation to temperamental negative affect/distress, no significant main effects or interactions were found. However, significant effects were found for infant soothability. Specifically, the Soothability × Emotion interaction was significant, $F(2, 74) = 4.58$, $p = .014$. When we examined the correlations between soothability and the Nc ERP difference scores, we found a significant correlation for the relative Nc amplitude for fearful faces ($r = .38$, $p = .017$) but not happy faces ($r = .01$, $p = .97$). As in chapter 3, the direction of the correlation implies that infants with lower soothability ratings had a larger (more negative) Nc amplitude to fearful faces, relative to neutral faces. Notably, this association was maintained after controlling for gender ($r = .40$, $p = .014$) and when trial count was partialed out (partial $r = .37$, $p = .023$).

5.3.2 Temperament × Parental Sensitivity Interactions

In order to test for interactions between temperament and parental sensitivity we entered main effects and product terms (Temperament × Sensitivity) as independent variables into regression analyses, with the relative Nc to fearful and happy faces (vs. neutral) as two separate dependent variables. These analyses were conducted separately for infant negative affect, soothability, and positive affect. No significant interactions were found.

5.3.3 Additional Nc Analysis

In chapter 4 maternal depression was associated with infants' neural responses at the Nc. Specifically, low levels of maternal depression were associated with infants' increased neural responses to positive emotion. Given the similar results reported in this chapter in relation to high levels of sensitive caregiving and infants' increased neural responses to positive emotion at the Nc, it seemed relevant to incorporate an analysis to assess whether these two associations are independent of each other. It should be noted though that the depression effect was restricted to the left hemisphere only, suggesting that they may be distinct effects; nevertheless, a regression analysis was conducted, controlling for maternal depression to see if the sensitivity effect remained. Notably, the association between maternal sensitivity and infant Nc responses to positive emotion remained significant after controlling for maternal depression (t = -2.51, p = .02).

5.3.4 Effects of Emotion, Laterality and Sensitivity on P400 Amplitude

The main effects for emotion ($F_{2,76}$ = .073, p = .930, η_p^2=.002) and laterality($F_{2,76}$ = .378, p = .542, η_p^2=.010) were not statistically significant. Nor was there a statistically significant interaction for parental sensitivity and the amplitude of the P400 infant ERP component ($F_{2,76}$ = 1.340, p = .268, η_p^2=.034). No further analysis was carried out.

5.3.5 Effects of Emotion, Laterality and Sensitivity on N290 Amplitude

The main effects for emotion ($F_{2,76}$ = .476, p = .623, η_p^2=.012) and laterality ($F_{2,76}$ = .003, p = .958, η_p^2=.000) were not statistically significant. Nor was there a significant interaction for parental sensitivity and the amplitude of the N290 infant ERP component ($F_{2,76}$ = 1.547, p = .220, η_p^2=.039). No further analysis was carried out.

5.4 Discussion

There has been increasing interest in the role of the environment in shaping neural development (Belsky & De Haan, 2011). Animal studies and studies of children exposed to extreme circumstances, such as institutional care or maltreatment, have provided quite good evidence regarding the functional (and in some cases structural) brain changes linked to highly adverse environments. Much less has been done to identify how more normative variations in the quality of early experience might influence brain development. In light of the highly consistent evidence concerning the developmental impact of variations in the sensitivity of parental care on emotional and behavioural development (Belsky & Fearon, 2002; Kertz, et al., 2008; Mäntymaa, et al., 2004; NICHD Early Child Care Research Network, 1999; Sroufe, 2005; Zhou, et al., 2002), understanding the neural systems influenced by this particular aspect of the early environment is an important goal for clinical child psychology and psychiatry.

As a first step towards that goal, we investigated 7-month old infants' neural responses to emotional expressions. Emotional faces are a very useful way to study infant brain responses in this context because a great deal of research has already characterised the typical ERPs evoked by faces and by emotional expressions in particular. Furthermore, and equally importantly, emotional facial expressions are of great significance as cues and social signals embedded within parent-infant interactions (Walden & Ogan, 1988) that infants are sensitive to from early in life (Field & Walden, 1982). Furthermore, there is good evidence at later stages of development that emotional face processing is altered among children and adults with behavioural and affective disorders (Blair, Colledge, Murray, & Mitchell, 2001; Dolan & Fullam, 2006; Marsh & Blair, 2008; Norton, et al., 2009; Sinzig, et al., 2008).

It is important here to note that even in this smaller sample presented in this chapter, larger Nc amplitudes were recorded in response to fearful faces compared to happy and neutral faces. This finding again adds to an extensive body of literature demonstrating the sensitivity of the Nc to differences in facial emotion expression (De Haan, et al., 2004; Leppänen, et al., 2007; Nelson & De Haan, 1996; Peltola, et al., 2009). Most importantly, when the magnitude of the Nc was examined for each emotional expression in relation to objectively assessed parental sensitivity a marked association was found for happy, but not fearful, facial expressions. Infants of mothers who were more sensitive and responsive during their interactions showed larger Nc neural responses to happy faces, relative to neutral faces. The finding would seem to suggest that sensitive parental responses to the infant's cues during interactions lead the developing brain to encode or evaluate emotional expressions differently, perhaps attaching greater motivational value to them. The finding is intriguing given the crucial role of positive emotional expressions in eliciting and reinforcing approach behaviour and social engagement (Feinman & Lewis, 1983; Seidel, Habel, Kirschner, Gur, & Derntl, 2010; Sorce, et al., 1985). One could speculate that during the course of warm, responsive and contingent (and therefore predictable) interactions the infant comes to encode positive emotional expressions as stronger cues to rewarding social interaction than those that experience less contingent, reciprocal and warm interactions. This in turn might affect how they attend to, interpret and engage in social interactions subsequently and bias behaviour and development in consistent ways. Another possibility of course is that sensitive parenting interactions may simply involve greater exposure, on the part of the infant, to positive emotional expressions, which then alters the infant's neural responding to that stimulus. One might question this interpretation because the effect we observed would seem more consistent with sensitization than habituation, in that higher sensitivity was associated with larger, not smaller, Nc amplitudes. However, there is evidence that repeated exposure can, under certain circumstances, heighten rather than diminish infant attention to a range of stimuli (De Haan & Nelson, 1999; Hunt, 1970; Hunter, Ross, & Ames, 1982; Roder, Bushnell, & Sasseville, 2000; Wagner & Sakovits, 1986), as well as neural responding to faces in particular (Carver, et al., 2003; Pollak, et al., 1997; Pollak, et al., 2001; Shackman, et al., 2007). Furthermore, despite the fact that the Nc is larger for fearful than happy or neutral faces (which should be more familiar), the Nc is also larger to mother's face than a stranger's, and to familiar relative to unfamiliar objects (De Haan & Nelson, 1997, 1999; Nelson, et al., 2000). Direct measurement of the frequency with which infants are exposed to different parental facial emotion expressions would be invaluable in this regard.

The overall pattern of our findings was quite different to those of De Haan et al. (2004). Not only did they not find any main effect of their indirect ‘marker’ of parenting (parental personality) on the Nc for happy faces, where they did find an association it was in relation to Nc amplitudes to fearful faces. In their study, among highly positive infants, higher maternal self-reported positive affect was associated with larger infant Nc amplitudes to fearful faces, which was interpreted as evidence that this expression may have been more novel for these infants. The two studies differ in numerous ways however, so direct comparisons are not possible. The key difference of course is that the measures of the environment were very different: De Haan et al (2004) relied on a measure of personality, while the current study measured distinct parenting behaviours directly. In addition to that crucial difference, De Haan et al. also did not analyse differences in EEG amplitude to neutral face stimuli, which may have limited the power of the statistical analyses to detect the relevant effects. Notably, both the De Haan et al. study and ours found evidence that temperamental dimensions broadly related to negative affect were associated with heightened Nc amplitudes to fearful faces. However, although soothability—the temperamental dimension linked to Nc amplitude in this study—is linked to negative emotion, it is by no means a direct assessment of negative emotionality, and as such our finding is clearly not a precise replication. Finally, it was notable that we did not find Temperament × Parenting interactions in this investigation, although the low power of tests of statistical interaction may be an important consideration in that regard.

It is important to consider why it might be that we did not find any association between parental sensitivity and infant neural responding to fearful faces. Several explanations are worth considering. First, positive emotional expressions are much more prevalent during early interactions than fearful ones (Malatesta & Haviland, 1982), and this, in and of itself, is a highly plausible explanation for the differential findings. If the effect we observed reflects a process of learning taking place during caregiving interactions, then the results may not be surprising, particularly in a low-risk sample, because positive expressions are likely to be the subject of more learning in the first half of the first year of life than fearful expressions. As noted already, it was notable that when we examined temperament we did find quite robust associations with Nc amplitudes to fearful faces, with infants scoring lower on soothability demonstrating larger neural responses to fear. Thus, it was not obviously the case that fearful faces are in some way less effective experimental stimuli (and indeed the larger neural response to fear faces also undermines the argument that the Nc might be noisier in this condition).

This is not the only study to highlight the potential importance of positive emotion in socio-emotional development and in the domain of parent-child relationships in particular (Chronis et al., 2007; Davidov & Grusec, 2006; Eisenberg, Gershoff, et al., 2001; Eisenberg et al., 2005). Intriguingly, in a recent very long-term prospective study Moutsiana et al. (2014) found that adults who 20 years earlier had been classified as insecurely attached as infants showed altered neural responding, relative to previously secure adults, in several brain areas (DmPFC, rACC) during an emotion-regulation task specifically when up-regulating positive emotion. The findings appeared to suggest that previously insecure adults had greater difficultly, and deployed greater cognitive effort, when upregulating positive emotions. Similarly, White and colleagues(2012) found reduced amplitude of reward-related ERPs among adolescents with insecure attachment styles. These studies collectively suggest that the sensitivity of parental behaviour may play a particularly important role in modulating the functioning of neural systems involved in approach, social engagement and reward. This evidence, considered alongside the findings presented in this investigation, could suggest that sensitive parenting and possibly secure attachment significantly influence positive emotional processing, either by altering the reward value of positive emotional expressions, enhancing the regulation of positive emotion or biasing attention to positive social signals. In this regard, the clinical implications arising from the data presented in this chapter primarily relate to promoting early intervention, with a specific focus on sensitive interactive caregiving. Tailored interventions that encourage a parent's awareness of their expressed emotional cues to related behaviour may be particularly important. More specifically, the data presented whereby infants who experience greater sensitive caregiving are neurologically sensitive to positive emotion, may indicate a need for clinical support to focus parents on the importance of expressed positivity and how this relates to positive, predictable and regulatory behavioural responses towards the infant.

5.5 Limitations:

It is important to note that this study has several limitations. First, the observational procedure used in this study, though employing a commonly used protocol and utilising a well-validated coding scheme, focuses on one particular set of parenting behaviours within a specific context (free-play), and was brief. It is therefore inevitable that it does not capture all the developmentally important variance in parenting sensitivity or in other domains of parental behaviour. Furthermore, the sample was restricted to a relatively advantaged, middle class population and the findings may not generalise to other populations. Further research on the neural effects of variations in parenting in more at-risk samples would be extremely valuable in the future. Also, our study reports on associations that were observed concurrently and at a specific point in development, and hence it will be important in future work to determine how stable and enduring such associations may be, and when they first arise. Finally, it is critical to note that although we have tended to interpret these findings as evidence indicative of an influence of the environment on brain function, these data are purely correlational and firm causal inferences cannot be made. In that regard, intervention studies that experimentally enhance the sensitivity of parenting would be exceptionally valuable in testing the causal nature of the associations reported here.

5.6 Summary and Conclusions

In conclusion, the current study found evidence in support of the view that the quality of early mother infant interactions may influence infants' brain responses to emotional expressions, and highlights the potentially important role of infants' neural coding of positive emotional expressions in particular. Replication of the current findings would be highly valuable, and future research may fruitfully explore other features of parenting, other domains of infant social-affective brain development and other populations. Studies will ultimately need to be done to test the causal nature of observed associations between parental care and infant brain development, in longitudinal and experimental studies.

6 The Importance of Infant Attachment on Infants' Neural Responses to Emotional Expressions

Through the course of this thesis, the findings of this study have pointed to the potential importance of the parent-infant relationship in shaping the neural pathways thought relevant for emotion processing in infants. Most critically, the findings from the last chapter suggested that in the context of supportive and responsive mother-infant interactions an infant may begin to encode positive emotions as highly salient cues that may lead them to become positively oriented to the social environment. A core construct within research on the early parent-infant relationship is attachment, which is arguably the most widely studied concept in the development psychology of early socio-emotional development. As such, the final empirical chapter in this thesis concentrates on the associations between attachment security and neural processing of emotion in infancy.

6.1 Introduction

Early experiences during infancy are widely believed to be a key influence on an individual's life trajectory. Substantial long-lasting consequences have been documented for emotional, social and cognitive development seemingly linked to variation in the quality of the early relationship between an infant and their caregiver (Belsky & Fearon, 2002; Kertz, et al., 2008; Mäntymaa, et al., 2004; NICHD Early Child Care Research Network, 1999; Sroufe, 2005; Zhou, et al., 2002). The developmental consequences of this early relationship can be seen to not only to shape psychological development but is also apparent at the neurobiological level (Bokhorst, et al., 2003; Lyons-Ruth & Jacobvitz, 2008; Schore, 1997, 2001, 2002; Siegel, 2001; Strathearn, et al., 2009). The parent-infant relationship of course subsumes a wide range of kinds of interactions and developmental functions, and a central one is that of attachment (Bowlby, 1958, 1973). Early caregiving interactions in which parental figures provide sensitive and appropriate responses to the child's attachment cues and needs is thought to lead the infant to develop a set of schemas – or mental representations - for guiding their behaviour and emotions in attachment contexts which have become known as "*internal working models*" (IWM). These IWMs consist of beliefs, thoughts, expectations, memories and emotions that are primarily shaped by the caregiver's response to their infant's attachment behaviour (Bowlby, 1973). It is these IWMs which are thought to underlie the behaviour an individual expresses in response to attachment related 'cues to danger', and is also thought to eventually guide a child's interpretation of, and behaviour within, a broader range of social interactions and relationships (Bowlby, 1973; Bretherton & Munholland, 2008). This theoretical understanding of the early parent-infant relationship has led to a great volume of research elucidating the importance of an early attachment with a primary caregiver in supporting later beneficial outcomes. In particular, a secure attachment to a primary caregiver is suggested to provide the necessary foundations thought relevant for later successful socio-emotional development (Sroufe, 2005).

A substantial number of empirical investigations have provided evidence to support this notion. Firstly, secure attachment is thought to be relevant in not only the forming of and maintenance of peer relationships (Elicker, et al., 1992; Freitag, et al., 1996; Grossmann & Grossmann, 1991; Lewis & Feiring, 1989; Sroufe, et al., 1999) but also in the quality of the close friendships they form (Kerns, 1994; Youngblade & Belsky, 1992). Furthermore, attachment security is predictive of later behavioural problems (Berlin & Cassidy, 1999a; Booth-LaForce & Kerns, 2009; Fearon, et al., 2010), with attachment disorganisation being robustly associated with later externalising symptoms (Fearon, et al., 2010). Early security is also predictive of better cognitive performance at school and higher IQ in middle childhood (Jacobsen & Hofmann, 1997; Moss & St-Laurent, 2001; West, Mathews, & Kerns, 2013). Further, infants who are classified as having a secure attachment to their primary caregiver have been found to respond in a less fearful and angry manner to laboratory episodes designed to elicit fear and anger emotions compared to insecure children (Kochanska, 2001). Overall, secure children tend to have a greater or more sophisticated understanding of emotion in general (Raikes & Thompson, 2006), particularly for negative emotions (Laible & Thompson, 1998). Finally, there is evidence that indicates that emotion regulation abilities are superior among children with histories of secure attachment (Braungart & Stifter, 1991; Cassidy, 1994; Diener, et al., 2002; Gilliom, et al., 2002; Leerkes & Wong, 2012; Moutsiana, et al., 2014).

It has been suggested that one of the fundamental interactive processes involved in the development of a secure attachment is the contingency between an infant's expressed emotion and the behavioural response from the parent (Gergely & Unoka, 2008). Contingency is the key mechanism in this social process between parent and infant and it is considered to be fundamental in the development of an infant's understanding of their internal emotional state (Fonagy, Gergely, & Target, 2007; Gergely & Watson, 1996, 1999). A parent's response to their infant's displays of affect is seen as a reflection of the parent's interpretation of their infant's emotional state. Successful perceptions of their infant's internal states, matched with appropriate contingent behaviour from the parent, are considered vital in the development of a secure attachment (Lyons-Ruth, et al., 1999). It is argued that through a parent's contingent response to their infant's cues, the infant begins to develop an understanding of emotion (Gergely & Watson, 1996, 1999). There is now clear empirical evidence to support this association between maternal contingent behaviour and attachment security. Specifically, Bigelow and colleagues (2010) found that maternal contingent vocalisations when interacting face-to-face with their four month old infants strongly predicted attachment security when measured at two and half years of age. Lyons-Ruth and colleagues (1999) have showed that specific affective communication errors from the parent, such as a positive response from the mother when the infant is distressed are associated with the degree of infant attachment disorganisation. Further yet, more recently, Miller (2008), found that maternal disrupted communication, such as a lack of maternal response to infant affect or a discrepant or aggressive response to infant distress, was predicative of infants disorganised attachment.

Thus, it is evident that the emotional response from a caregiver during interactions with their infant is influential in shaping an infant's early attachment. Further yet, there is substantial evidence in highlighting the ways in which this early attachment, and by extension, secure IWMs, may be linked to the development of more optimal emotion processing and subsequent behaviour. Despite this seemingly obvious association between emotion and early attachment there is very limited research looking at how infants directly encode emotion and how this relates to their attachment status.

The relationship between attachment and emotion processing has been addressed in the adult literature. Fraley and colleagues (Fraley, Niedenthal, Marks, Brumbaugh, & Vicary, 2006) found that adults who were rated as more anxiously attached in their relationships were less accurate in identifying emotion than those who were less anxiously attached. Furthermore, anxiously attached individuals perceived the onset and offset of emotional expressions faster in a face morphing paradigm. Dewitte and Houwer (2008) showed that those classified with an anxious attachment combined with high avoidance, display reduced attention towards angry facial expressions as well as more orientation away from happy facial expressions. This observational evidence is further strengthened by recent neuroimaging investigations. Individuals with insecure attachment classifications are argued to exhibit altered neural responses to facial displays of affect compared to those classified as securely attached (Donges et al., 2012; Moutsiana, et al., 2014; Suslow et al., 2009). Specifically, Vrtička and colleagues (2008) found that individuals who were classified as anxiously attached, in fact displayed increased neural activity of the left amygdala in response to angry faces (Vrtička, Andersson, Grandjean, Sander, & Vuilleumier, 2008). Furthermore, a long-term prospective study by Moutsiana et al. (2014) found altered neural responding in several brain areas (DmPFC, rACC) when up-regulating positive emotion during an emotion-regulation task for those adults who were classified as insecurely attached during infancy compared to those previously classified as secure.

Collectively these findings provide good convergent evidence that individual attachment styles are neurologically sensitive to, or process differently, displays of emotion. What remains relatively unknown is whether indeed these neural differences involved in emotion processing in relation to variations in attachment, can be indexed during infancy. To date no study has directly assessed infants' neural correlates to emotional faces in relation to their attachment classification.

There is, although limited, some observational investigations that have looked at the relationship between attachment and emotion processing in children, in fact to date there are only two studies that have attempted to assess this possible association. Firstly, Steele and colleagues (2008) analysed data from a longitudinal study relating attachment status measured during infancy to emotion recognition at age 6 years old. Steele et al., found that infants classified as insecure-resistant had the greatest difficulty in judging happy emotional faces, with only 38% of previously categorized resistant children correctly identifying happy facial expressions at 6 years old. Furthermore, 100% of children with a resistant history were unable to identify a surprised facial expression. Interestingly, children who had a categorisation of disorganisation were able to accurately judge emotional faces to the same extent as those that had a history of security. The authors conclude that this is due to a hyper-vigilant response to all emotions, due to the unpredictability of experienced emotion in those children previously assessed as disorganised. However, Steele's interpretation would seem to contradict evidence from clinical populations, who inherently have a higher prevalence of disorganisation (Cyr, et al., 2010; Vorria et al., 2003; Zeanah, Smyke, Koga, & Carlson, 2005), showing an increased sensitivity to negative facial expressions over and beyond other facial expressions (Maheu, et al., 2010; McCrory, et al., 2013; McCrory, et al., 2011; Pollak, et al., 1997; Pollak & Kistler, 2002; Shackman, et al., 2007; Tottenham, et al., 2011). The second, more recent study relating the processing of emotional faces to attachment comes from Peltola and colleagues (2015). Peltola et al. directly assessed whether 7 month old infants' attention to facial displays of emotion, using an eye tracking paradigm, was associated with infants' attachment status measured using the strange situation at 14 months of age. Peltola et al. found that insecure attachment patterns were predicable from those infants who had a smaller attentional bias to fearful facial expressions. Interestingly, higher levels of attachment disorganization were significantly related to a diminished attentional bias to fearful facial expressions. This study by far provides the strongest evidence for a relationship between infant attachment security and emotion processing.

The aforementioned research provides some useful evidence relating an infant's ability to process displays of emotion and the attachment to their primary caregiver. This, alongside the neural evidence from investigations with adults, makes it plausible to expect that differences in attachment classification during infancy would be related to infants' neural correlates involved in emotion processing. Currently there is no study to date that has assessed the influence of attachment patterns on infants' current neural processes thought relevant for emotion processing. There is clear neurological evidence highlighting early appearing emotional face recognition skills in infancy (De Haan, et al., 2003; Nelson, 1987; Peltola, et al., 2009), given this, alongside the theoretical and empirical understanding of the importance of emotion in relation to attachment, it feels necessary to draw these two complementary trains of thought together.

As the previous chapters in this thesis have shown, using neural responses in the form of ERPs to emotionally significant stimuli - emotional faces - we are not only able to directly tap into the mechanisms thoughts relevant for emotion processing but are able to assess how environmental factors may influence such mechanisms. As such, the final empirical chapter in this thesis aims to draw on one of the most influential models in developmental psychology, *attachment*, in assessing its contribution to the neurological processing of emotion in infants. Specifically, this chapter will assess ERP responses in 7 month old infants to facial displays of emotion in relation to attachment classifications assessed at 12 months of age. Two main hypotheses seem relevant in regards to the reviewed literature above, 1) Insecure attachment classification will relate to smaller amplitudes to negative emotional expressions at the attention allocation ERP component the Nc and (2) secure attachment classification will relate to larger Nc ERP amplitudes to negative over positive emotional expressions. This study has the potential to not only bridge a clear gap in the attachment literature but also to shed light on the role that attachment has in shaping key early-appearing social-cognitive and affective mechanisms in infancy, such as emotion processing.

6.2 Method

6.2.1 Participants

For a full description of the recruitment method please see chapter 2. This sample is the same sample used in the previous chapters of this thesis, with an initial sample of 130 parent-infant dyads from the local community. Seventy one out of the 130 infants had useable EEG data. As previously mentioned this rate of attrition is in line with other infant EEG experiments (De Haan, et al., 2004; Leppänen, et al., 2007).

Out of the remaining 71 dyads, three were unable to be coded for attachment status (one, unclassifiable and two procedural error). The remaining sample consisted of 68 healthy mother-infant dyads. All infants were considered to be born full term (i.e. 37-42 weeks gestation) and of normal birth weight (>6 lbs, 2 oz). Infants mean age at the 7 month assessment was 230 days (33 females and 35 males). For a full sample description please see Table 6-1.

Table 6-1 Sample Description

Sample Description	
N = 68	
Mother age in years:	
Mean (SD)	34.7 (4.3)
Range	20.8 - 50.5
Child gender: N (%)	
Female	33 (49%)
Male	35 (51%)
Number of other children: N (%)	
First time mothers	52 (77%)
More than one child	13 (19%)

Missing	3 (4%)
Mother ethnicity: N (%)	
White	58 (85%)
Black	1 (2%)
Asian	3 (4%)
Mixed	2 (3%)
Other	1 (2%)
Missing	3 (4%)
Mothers' education N (%)	
Secondary School	2 (3%)
Further Education	5 (7%)
Higher Education	57 (84%)
Missing	4 (6%)
Mothers' Employment N (%)	
Employment	53 (78%)
Unemployment	11 (16%)
Missing	4 (6%)
Household Income N(%)	
Below £30,000 per year	5 (7%)

Above £30,000 per year	56 (83%)
Missing	7 (10%)

6.2.2 Measures

The Strange Situation: The Strange Situation Procedure (SSP; Ainsworth, et al., 1978) is one of the most widely used assessments to categorise an infant's attachment behaviour to their caregiver. Through a series of separations and reunions between the infant and caregiver (at times with an unknown adult, the "stranger") a trained reliable coder is able to categorise the infant's behaviour. In particular, there are 8 episodes in total, including 2 separation episodes and 2 reunions episodes. The purpose behind these separations is to produce mild levels of fear in the infant, such that the infant's attachment system is triggered. Assessments are coded by trained researchers who are reliable with the authors' classifications. In the first instance a rating of *secure (B)* or *insecure(A or C)* is attributed to the infant's response, followed by sub classifications, A1-A2, B1-B4 and C1-C2 depending on specific behaviours witnessed in reunions episodes. Finally a *disorganised (D)* level (1-9) is assigned with scores of 5 and above resulting in a *Disorganised* classification. The stability of the Strange Situation has been shown in both US and non-US samples (Main & Cassidy 1988 88, Warner 1994). In non-clinical samples the global distribution of attachment classification is suggested to be 62% are classified as secure; 9-10% as resistant; 15% as avoidant; 14-15% as disorganised(van IJzendoorn, et al., 1999). Secure versus insecure groups were comparable across maternal age, maternal employment, maternal level of education and infant gender. Please see table 6-2 and 6-3 for this samples distribution and between group comparisons.

A secondary coder was used to assess the reliability of the primary coder for a subset of 15 cases. The Kappa statistic was performed to determine consistency among raters. High inter-rater agreement was obtained on the four major classifications, ABCD - Kappa = 0.859 (p <.0.000).The inter-rater reliability for secure versus insecure classification for the raters was found to be Kappa = 0.837 (p <.0.001).

Table 6-2 Classification Distribution

Attachment Security Classification Distribution	**N (%)**
Secure	48 (71%)
Insecure	20 (29%)

Attachment Sub-Classification Distribution	**N (%)**
Secure (B)	48 (71%)
Avoidant (A)	11 (16%)
Resistant (C)	5 (7%)
Disorganised (D)	4 (6%)

Table 6-3 Attachment Group Comparisons

Attachment Group Comparisons			
	Secure	**Insecure**	***t* (d.f.)**
Maternal Age	34.12 (3.92)	36.19 (5.00)	-1.75 (62)
	Secure	**Insecure**	**χ^2 (d.f.)**
Employment (employed)	*n* = 39 (85%)	*n* = 14 (78%)	*.45 (1)*
Education (degree)	*n* = 41 (87%)	*n* = 16 (94%)	.61(1)
Infant Gender	Male = 28 (58%)	Male = 7 (35%)	3.07 (1)

** p < .01.

6.2.3 Procedure

Parents who agreed to take part in the study visited the laboratory twice. First when their infants were 7 months old and then again when their infants were 12 months old. Parents were provided with a written and verbal description of the full experimental procedure and gave written informed consent at the 7 month appointment for procedures that would be carried out at both visits. As previously described, the 7 month visit consisted of the EEG recording, which on average lasted about 20 minutes including net application and a recording of 3 minutes of resting data. The experiment consisted of one block of 210 face trials (70 Happy, 70 Fearful and 70 neutral). Each trial was 500 milliseconds long and was presented randomly. The inter-stimulus interval varied randomly between 500 and 1000ms. Trials began once the infant's attention was drawn to the screen. The infant's behaviour was monitored by a researcher who activated a bright colourful animation if the infant became fussy to redirect the infant's attention to the screen. When an infant's attention could no longer be redirected to the monitor, the session was terminated. Parents were instructed to not interact with their infant at all during the session, and were told that if their infant turned to look at them they were to avoid eye contact and look straight ahead.

Parents were contacted again when their infants turned 12 months old and invited back to the lab to complete the Strange Situation Procedure. The Strange Situation Procedure was carried out in a purpose built baby-friendly room that adhered to the guidelines of the SSP methodological setup.

6.2.4 Emotion Stimuli

As previously mentioned the emotional stimuli consisted of 5 female actors each posing a happy, neutral or fearful face (210 total trials). The faces were posed against a white background and were cropped so no hair or other features could be seen. The static images were centrally positioned and measured 12cm x 9cm on a 10.5 inches x 13.5 inches on the screen. The stimuli were provided by the MacBrain Face Stimulus Set. Development of the MacBrain Face Stimulus Set was overseen by Nim Tottenham and supported by the John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development.

6.2.5 EEG recording

EEG was recorded continuously during the face viewing trials using a 128 hydrocel geodesic net (Electrical Geodesic Inc. Eugene, OR) referenced to the vertex (Cz). The electrical signal was amplified with a 0.1-to 100-Hz band-pass with a sampling rate of 250Hz. All EEG data were analysed offline using the EEG platform EEGLAB (Delorme & Makeig, 2004), and in-house custom made MATLAB scripts.

6.2.6 Data reduction

The data reduction technique is the same as that reported in previous chapters. For each participant the EEG signal was segmented into an epoch ranging from 100ms before stimulus onset and extending to 750ms after stimulus onset. Before any EEG data was analysed, the video recording of the infant was examined thoroughly and segments were rejected when the infant was not looking at the screen. The remaining digitally filtered (0.1Hz-30Hz) and baseline corrected segments were visually inspected for artefacts relating to movement or high frequency noise. Bad channels were identified and replaced using spherical spline interpolation. Segments that displayed large artefact or high frequency noise were removed from further analysis. Independents component analysis was run using FASTER to remove stereotyped artefacts (Nolan, et al., 2010). Finally, with a minimum of 10 trials per experimental condition, the data was averaged and re-referenced to the average reference. The average number of good trials for this sample set was 22 (SD = 7.9, range = 10- 48) for fearful faces, 23 (SD=8.4, range=10 - 45) for happy faces and 21 (SD=7.6, range =10- 43) for neutral faces. Again, this attrition is consistent with other infant ERP studies (De Haan, et al., 2004; Leppänen, et al., 2007).

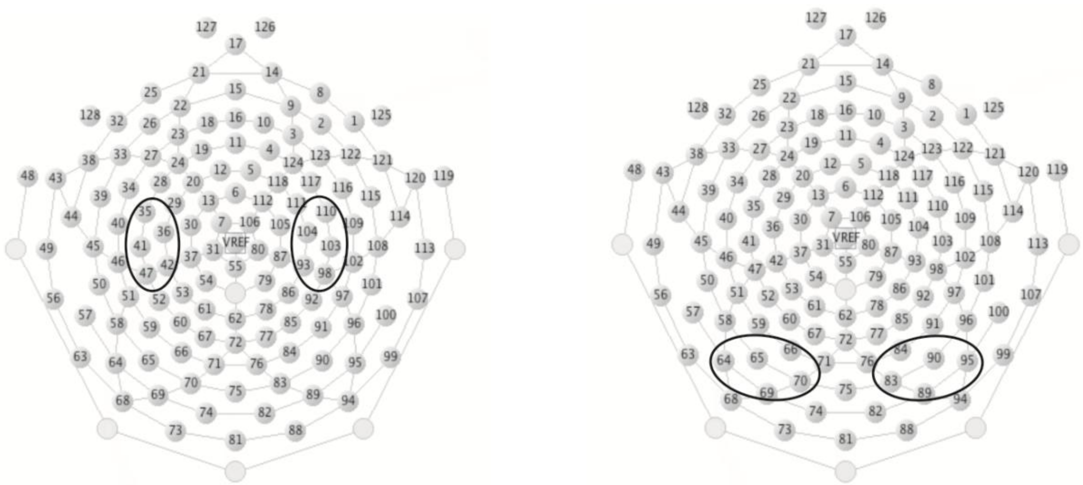
6.2.7 Statistical Analysis:

As in previous chapters, the following three infant ERP components were chosen Negative Central (Nc), the P400 and the N290 for analysis. Time windows for all three infant ERP components, the Nc, P400 and N290 were created by examining the grand average waveform for all participants and looking at past studies' selected time windows.

Negative Central (Nc): The central electrode clusters for the Nc is; left: 35, 41, 36, 47, 42 and right: 110, 104, 103, 93, 98. Time window: 350ms after stimulus onset to 650ms after stimulus onset.

N290 and P400: For the N290 and P400 the posterior lateral electrodes clusters for both components were; left: 66, 70, 65, 69, 64 and right: 84, 83, 90, 95, 89. Time window for the P400 was 350ms after stimulus onset and extended to 600ms after stimulus onset and for the N290, 250ms after stimulus onset to 350ms after stimulus onset. See figure 6-1 for channel cluster locations.

Figure 6-1 Selected Channel Clusters



Negative Central (Nc)

N290 & P400

Analysis of amplitudes for all components, N290, P400 and the Nc, involved the use of mixed 2x3x2 ANOVAs. The within subject variables consisted of three emotional expressions (fearful, happy and neutral) and hemisphere (left and right). The between subject factor consisted of infant attachment classification (secure vs insecure).

6.3 Results

6.3.1 Emotion Effect and Infant ERPs:

Consistent with the results previously reported in chapters 3 to 5, the significant effect of emotion was found for the Nc ERP component ($F_{2,132}$ = 5.190, *p* = .01, η_p^2=.07). Fearful faces elicited larger amplitudes (*M* = -5.09) than Happy (*M* = -3.92) and neutral (*M* = -3.75) faces. The main effect for laterality at the Nc was not statistically significant ($F_{1,66}$ = .25, *p* = .68, η_p^2=.00). Replication of the null result for emotion for the N290 and P400 was equally found in this data ($F_{2,132}$ = .68 *p* = .51, η_p^2=.01 and $F_{2,132}$ = .91, *p* = .40, η_p^2=.01 respectively).

6.3.2 Effects of Attachment, Emotion and Infant ERPs

Nc Amplitude and Attachment: The interactions between emotion and attachment classification ($F_{2,132}$ = 2.05, *p* =.13, η_p^2=.03) and laterality and attachment classification were not significant ($F_{1,66}$ = .41, *p* =.53, η_p^2=.01) . Nor was there a significant interaction between emotion, laterality and attachment ($F_{2,132}$ = .904, *p* =.61, η_p^2=.01).

Table 6-4 Descriptive Statistics Attachment Security and Nc Mean Amplitudes

Attachment Security and Nc Mean Amplitudes

	Left Hemisphere			Right Hemisphere		
	Fear	**Happy**	**Neutral**	**Fear**	**Happy**	**Neutral**
Secure	-4.83	-4.62	-3.10	-4.77	-4.26	-3.87
N=48	(SD=5.18)	(SD=5.76)	(SD=5.18)	(SD=5.51)	(SD=4.20)	(SD=4.99)
Insecure	-6.21	-3.57	-4.48	-4.57	-3.23	-3.53
N=20	(SD=6.25)	(SD=6.59)	(SD=6.07)	(SD=4.67)	(SD=4.57)	(SD=4.12)

Table 6-5 Descriptive Statistics Attachment Sub-classifications and Nc Mean Amplitudes

Attachment Sub-classifications and Nc Mean Amplitudes

	Left Hemisphere			Right Hemisphere		
	Fear	**Happy**	**Neutral**	**Fear**	**Happy**	**Neutral**
Avoidant	-6.34	-4.07	-5.23	-4.60	-3.33	-4.31
N=11	(SD=7.06)	(SD=7.50)	(SD=7.27)	(SD=4.12)	(SD=5.51)	(SD=5.05)
Secure	-4.83	-4.62	-3.10	-4.77	-4.26	-3.87
N=48	(SD=5.18)	(SD=5.76)	(SD=5.18)	(SD=5.51)	(SD=4.20)	(SD=4.99)
Resistant	-6.10	-4.30	-4.03	-1.18	-2.74	-2.36
N=5	(SD=4.78)	(SD=3.35)	(SD=4.70)	(SD=3.81)	(SD=3.70)	(SD=2.53)
Disorganised	-5.98	-1.28	-2.99	-8.74	-3.57	-2.82
N=4	(SD=7.14)	(SD=8.00)	(SD=4.74)	(SD=4.46)	(SD=3.50)	(SD=2.94)

Nc Amplitude, Maternal Sensitivity and Attachment: Given the relationship between maternal sensitivity and infant attachment classification (De Wolff & van IJzendoorn, 1997), and the previous results reported in chapter 5 relating maternal sensitivity to infants' neural processing of emotion at the Nc, it seemed relevant to incorporate an analysis using the smaller sample of 40 infants from chapter 5 who also had attachment classifications. Out of the 40 infants, 37 had Strange Situation data the distribution of classification was: B = 24 (65%) A = 8 (22%) C = 3 (8%) and D = 2 (5%), secure (65%) and insecure (35%). In the smaller dataset of 37 cases, infant attachment classification was marginally associated with maternal sensitivity (t (16.23) = 1.98., p = .06). The significant findings in chapter 5 were restricted to the Nc and positive emotion only and as such, this was the focus of this additional analysis.

Regression analyses were carried out to establish whether the previously reported sensitivity effect was independent of infant attachment classification at the Nc. For the smaller sample of 37 cases which had both sensitivity scores and attachment classification, the relative Nc amplitude to positive emotion again correlated to maternal sensitivity (r = -.37, p = .02). When controlling for attachment the result became marginally significant (t =*-1.93*, p = .06) suggesting that when attachment is factored in the effect is reduced – suggesting some overlapping variance between the two that is linked to the Nc response. However, given the absence of an effect of attachment and the marginal significance of the sensitivity effect, it seems prudent to assume that the sensitivity effect is largely independent of attachment.

P400 Amplitude and Attachment: The interactions between emotion and attachment classification ($F_{2,132}$ = .17, p =.85, η_p^2=.00) and laterality and attachment classification were not significant at the infant P400 ($F_{1,66}$ = .29, p =.59, η_p^2=.00) . Nor was there a significant interaction between emotion, laterality and attachment at the infant P400 ERP component ($F_{2,132}$ = .15, p =.86, η_p^2=.00).

Table 6-6 Descriptive Statistics Attachment Security and P400 Mean Amplitudes

Attachment Security and P400 Mean Amplitudes

	Left Hemisphere			Right Hemisphere		
	Fear	**Happy**	**Neutral**	**Fear**	**Happy**	**Neutral**
Secure	14.30	13.90	12.71	13.90	13.24	12.56
N=48	(SD=9.44)	(SD=8.98)	(SD=7.94)	(SD=9.31)	(SD=10.39)	(SD=10.27)
Insecure	15.44	14.69	14.32	16.60	14.59	15.33
N=20	(SD=9.97)	(SD=8.63)	(SD=8.30)	(SD=10.63)	(SD=9.97)	(SD=9.15)

Table 6-7 Descriptive Statistics Attachment Sub-classifications and P400 Mean Amplitudes

Attachment Sub-classifications and P400 Mean Amplitudes

	Left Hemisphere			Right Hemisphere		
	Fear	**Happy**	**Neutral**	**Fear**	**Happy**	**Neutral**
Avoidant N=11	12.75 (SD=10.32)	13.34 (SD=8.38)	14.66 (SD=9.60)	14.23 (SD=10.41)	14.26 (SD=9.84)	16.22 (SD=8.27)
Secure N=48	14.30 (SD=9.44)	13.90 (SD=8.98)	12.71 (SD=7.94)	13.90 (SD=9.31)	13.24 (SD=10.39)	12.56 (SD=10.27)
Resistant N=5	19.15 (SD=8.08)	17.87 (SD=8.44	15.44 (SD=9.07)	17.69 (SD=8.78)	17.18 (SD=10.04)	13.54 (SD=10.65)
Disorganised =4	18.19 (SD=11.31)	14.43 (SD=10.92)	12.01 (SD=3.16)	21.72 (SD=13.96)	12.24 (SD=12.36)	15.09 (SD=11.96)

N290 Amplitude and Attachment: The interactions between emotion and attachment classification ($F_{2,132}$ = .30, *p* =.74, η_p^2=.01) and laterality and attachment classification were not significant at the infant N290 ERP component ($F_{1,66}$ = .55, *p* =.46, η_p^2=.01). The interaction between emotion, laterality and attachment classification was not significant at the infant N290 ERP component ($F_{2,132}$ = .01, *p* =.99, η_p^2=.00).

Table 6-8 Descriptive Statistics Attachment Security and N290 Mean Amplitudes

Attachment Security and N290 Mean Amplitudes

	Left Hemisphere			Right Hemisphere		
	Fear	**Happy**	**Neutral**	**Fear**	**Happy**	**Neutral**
Secure N=48	5.13 (SD=8.37)	5.05 (SD=8.38)	4.46 (SD=7.77)	4.62 (SD=7.25)	3.79 (SD=7.86)	3.97 (SD=6.91)
Insecure N=20	5.52 (SD=7.80)	4.04 (SD=7.40)	4.82 (SD=8.61)	6.07 (SD=6.60)	3.98 (SD=75.97)	5.33 (SD=6.92)

Table 6-9 Descriptive Statistics Attachment Sub-classification and N290 Mean Amplitudes

Attachment Sub-classifications and N290 Mean Amplitudes

	Left Hemisphere			Right Hemisphere		
	Fear	**Happy**	**Neutral**	**Fear**	**Happy**	**Neutral**
Avoidant N=11	3.58 (SD=8.90)	3.64 (SD=7.56)	6.81 (SD=10.50)	4.59 (SD=5.61)	4.38 (SD=4.48)	6.84 (SD=6.01)
Secure N=48	5.13 (SD=8.37)	5.05 (SD=8.38)	4.46 (SD=7.77)	4.62 (SD=7.25)	3.79 (SD=7.86)	3.97 (SD=6.91)
Resistant N=5	7.17 (SD=7.06)	4.09 (SD=8.89)	1.61 (SD=6.66)	5.20 (SD=6.76)	4.68 (SD=8.81)	1.57 (SD=8.88)
Disorganised N=4	8.78 (SD=4.69)	5.06 (SD=7.00)	3.3 (SD=2.77)	11.19 (SD=8.12)	2.01 (SD=6.99)	5.86 (SD=6.71)

6.4 Discussion

Decades of research in the field of developmental psychology have pointed to the significant advantages that a secure attachment between an infant and their primary caregiver has for an individual's life trajectory (Sroufe, et al., 2005). The formation of this relationship, which begins in the first year of life, is shaped through an individual's exposure to contingent sensitive parental behaviour that is partly expressed through non-verbal cues, such as facial displays of affect. The impact that the early attachment relationship has on the neural mechanisms thought relevant in processing such emotional expressions in infancy remains uncertain. By studying infants' neural responses to emotional expressions in relation to their attachment status we can begin to disentangle the complex relationship between early attachment and emotional development. As such, this study sought to provide new evidence regarding the processes by which early attachment relates to the neural mechanisms involved in emotion processing. Based on previous literature, we hypothesized that secure attachment classification would relate to larger Nc ERP amplitudes to negative over positive emotional expressions.

There was no significant effect of infant attachment classification in relation to infants' neural processing of emotion. Contrary to prediction, fearful faces did not elicit greater neural responses at the infant Nc in among infants with secure attachment classifications compared to insecure ones. The lack of a statistically significant association between infants' ERP responses to emotional faces and attachment classification is surprising, particularly given the substantial empirical evidence that has related attachment classification to attachment-relevant social and emotional information processing (for a review see Dykas & Cassidy, 2011). More specifically, there is very recent evidence by Peltola and colleagues (2015) in which attachment security was associated with infants' attentional bias to emotional faces. However, the data presented in this study suggests that infants' ability to process emotional face stimuli is unrelated to infant attachment classification, at least at the neural level indexed by ERPs.

First and foremost, this study hypothesised that fearful faces would elicit larger amplitudes at the infant Nc for those who were classified as securely attached compared to insecure infants. This study failed to show this association. It is important to note that this lack of association was unlikely to be driven by ineffective emotional stimuli, as indeed fearful faces elicited the typical response of greater amplitudes at the Nc for all infants (De Haan, et al., 2004; Leppänen, et al., 2007; Nelson & De Haan, 1996; Peltola, et al., 2009). However, in this study this effect appears not to be sensitive to infant attachment classification. The data presented in this study is not the first to indicate a lack of variation between attachment classifications and emotion processing. Indeed, Steele and colleagues (Steele, et al., 2008) although finding differences between secure and resistant infants in how they categorise positive emotional faces, reported no differences between disorganised infants and secure infants in how they identified a range of emotional faces.

The lack of a statistically significant association between infant attachment classification and infants' ERP responses to emotional faces may primarily be due to the relatively skewed attachment classification distribution. Infants classified as having a secure attachment to their caregiver represented 71% of participants in this study, in contrast to the global distribution of 62% in non-clinical populations (van IJzendoorn, et al., 1999). With this in mind, it is important here to consider the results in this study alongside those reported by Peltola et al. (2015). Peltola and colleagues study, in which attachment classification measured at 14 months was associated with infants' attention towards fearful faces at 7 months, incorporated a sample that had a higher prevalence of insecure infants. In particular, insecure infants represented 40% of their sample compared to 29% of insecure infants in the current study. Furthermore, supplementary analysis by Peltola and colleagues showed that the high level of disorganised behaviour was related to a diminished attentional bias towards fearful faces. Given that their study had a more typical prevalence of infants classified as disorganised, 11%, compared to 6% of disorganised infants in this study, direct comparisons should be made tentatively. It simply may be that this study failed to provide a typical non-clinical attachment distribution and as such, the biased sample is in part responsible for the null effect.

It is particularly surprising that our study did not find statistically significant differences related to attachment in the attention allocating ERP component, the Nc, given that Peltola and colleagues found significant variation in attentional bias to fearful faces in relation to infant attachment classification by measuring looking time responses. Despite the aforementioned differences in the distribution of attachment classifications between their study and the current study, there are clear methodological differences between these two studies and as such, direct comparisons are not possible. For example, there is evidence from a study that utilized both methodological procedures, a looking-time and an ERP paradigm, (Leppänen, et al., 2007) to asses emotion processing with infants of 7 months of age that showed the two indices may not correlate at all. Thus, it can be argued that the different measures are sensitive to different processes related to emotion processing and as such, Peltola's study and the current study are possibly capturing different emotion processing effects in relation to infant attachment classification. In line with this thinking, it is interesting to hypothesize that perhaps infants' neural processing of emotion in relation to their attachment status is sub-served by subsequent neural processes that are not differentiated in immediate infant face ERPs. As such, it may be that the neural indices employed in this study were not sensitive enough to capture possible differences in infants processing of emotion in reference to their attachment status. Indeed, the two limitations discussed above – possible insensitivity of the neural markers and biased distribution of attachment classifications, may also be compounded by the categorical nature of attachment, as typically measured, in contrast, for example to maternal sensitivity. Categorical data inevitably reduces statistical power, and the sample size may not have been sufficient to detect reliable associations.

Data presented in the previous chapters in this thesis suggested that infants' neural processing of emotion was sensitive to early environmental experiences, and this may partly be due to individual differences in exposure to specific emotional faces. In other words, it may be that familiarity is driving the significant differences in ERP responses to emotional faces. Secure attachment, however, cannot be understood by reference to experienced emotional faces in as straightforward a way as sensitive caregiving and maternal mental health can be. For example, the meta-analytic association between attachment and sensitivity is relatively low ($r = .24$; De Wolff & van IJzendoorn, 1997) implying that there is still a lack of understanding in regards to the interactive determinants most closely linked to attachment security and insecurity. Unlike parental sensitivity, whereby validated measures, such as the Emotional Availability Scales, are able to capture differences in emotional expressiveness, when it comes to attachment this is much less clear. As such, being able to predict more definitively the exposure secure infants have to specific emotional faces is more complex.

Although attachment did not appear to be reliably associated with infant ERP responses, it is nevertheless interesting to ask whether the previously-reported association between maternal sensitivity and infant's neural responses to happy faces held up after attachment had been controlled for, given their mutual association in previous research (Ainsworth, et al., 1978; De Wolff & van IJzendoorn, 1997). Interestingly, when controlling for attachment the sensitivity effect became marginally significant indicating that there may be some overlapping variance between attachment and maternal sensitivity that is association with the Nc response to positive emotion. However, given that there was an absence of an attachment effect and the marginal significance in regards to the sensitivity effect, it is within good reason to assume that the sensitivity effect is largely independent of attachment. A larger sample size would be extremely beneficial in determining whether sensitivity and attachment have overlapping associations with the Nc or whether sensitivity is in fact independent of attachment.

Finally, it is also worth considering that perhaps studying infants' ERPs to emotional faces at 7 months of age in relation to attachment security assessed at a later age of 12 months may have also contributed to the null finding. Although attachment researchers suggest that infant attachment-related behaviours are evoked as early as 7 months of age (Bowlby, 1969; V. Prior & Glaser, 2006), it is not until the end of the first year that infants display clear goal-directed attachment behaviours to a preferred caregiver (Maintenance of proximity to a discriminate figure by means of locomotion as well as signals –Bowlby, 1969). With this in mind, it is possible that infants' neural sensitivity to displays of emotional faces were unrelated to attachment classification as a result of the methodological design of this study. Measuring both infants' attachment status and their ERPs to emotional faces concurrently at 12 months of age may prove an interesting direction for future research.

Overall, the lack of a significant association between attachment security and infants' neural responses to emotional faces could be seen as insightful for clinicians when approaching clinical practice with young infants and parents. Specifically, the null effect seen in this study (although still requiring confirmation through replication) may reflect the complexity of the early attachment relationship and its interactive determinants. Evidently much less is known about the role that emotional expressions play in the attachment relationship compared to the role that expressed affect plays in assessing sensitive caregiving. As such, when assessing and interpreting the role of expressed emotion in relation to attachment, caution is necessary.

6.5 Limitations

This study is not without its limitations, as has been noted already. Firstly, the sample used in this study was restricted to an advantaged middle-class population which limits the generalisability of the findings. Although a normative perspective is highly valuable and sought after, the sample used was relatively biased to an upper middle-class sample and did not fully capture the diversity of more typical normative samples. Secondly, despite the comparatively large sample size for an infant ERP study, 68 infants in total, the distribution of insecure versus secure is still relatively skewed. In particular, this sample presented 71% infants as securely attached as opposed to the global distribution of 62% (van IJzendoorn, et al., 1999). This may be due in part to the middle-class sample assessed. Future investigations that incorporate more insecurely attached infants are necessary. In particular, an increase in insecure participants would ultimately involve a wider selection of the sub-classifications of insecure attachment patterns, which may prove extremely important (for example disorganization in particular). A larger sample incorporating both maternal sensitivity and infant attachment classification in relation to infants' ERPs to emotional facial expressions may not only provide a more robust test of the association between attachment and emotion-related EPRs, but also into the role of sensitive caregiving in mediating a possible relationship between infant attachment classification and infants neural processing of emotion.

6.6 Summary and Conclusion

This study is the first to assess infants' neural responses linked to emotional processing in relation to infants' attachment classifications in a non-clinical population. In summary, infants' attachment classifications, assessed at 12 months of age, were unrelated to their ERPs to emotional facial expressions when measured at 7 months of age. Given the limitations of the measures and sampling, caution must be maintained when interpreting these results as a true null finding. Most importantly, given the sample bias towards secure infants the results reported in this study must be considered as preliminary and in need of replication to substantiate a true null effect.

7 General Discussion

7.1 Introduction:

In the field of developmental psychology it is widely acknowledged that the early parent-infant relationship plays an important role in an individual's life trajectory (Bokhorst, et al., 2003; Bowlby, 1958, 1982; Bretherton & Munholland, 2008; Lyons-Ruth & Jacobvitz, 2008; Schore, 1997, 2001, 2002; Siegel, 2001; Strathearn, et al., 2009; Swain, et al., 2007). More than six decades of theoretical and empirical research has allowed researchers to explore this contribution of early relationships to later development empirically using a wide range of methods and in a wide range of contexts. Although many later outcomes have been assessed in relation to the early parent-infant relationship (for a review see Thompson, 2008), later social and emotional functioning appears to be the most commonly studied (Belsky & Fearon, 2002; Kertz, et al., 2008; Mäntymaa, et al., 2004; NICHD Early Child Care Research Network, 1999; Sroufe, 2005; Zhou, et al., 2002). Attachment theory and research has arguably made the most significant contribution to this area of investigation. Secure attachment formed with a primary caregiver during infancy is widely believed to promote successful social and emotional development (Sroufe, 2005) . An impressive evidence base of longitudinal studies has tested this broad notion in relation to social competence, behavioural problems and internalizing problems (Fearon, et al., 2010; Groh, et al., 2014; Groh, et al., 2012), and broadly speaking the evidence supports the existence of longitudinal connections between early attachment and later outcome. Behavioural investigations focused on outwardly observable behaviour (often relying on parent self-report for outcome assessments) have been the backbone to this work. More recently, neuroscientific techniques have begun to be used in developmental research as indices or markers of processes related to the parent-infant relationship and the systems influenced by it. The neural imprint of early experiences has become an increasingly important and growing area for research. Important examples include studies that have investigated the neural changes associated with rearing in highly atypical environments, such as institutional care and maltreatment (Belsky & De Haan, 2011; Cicchetti & Curtis, 2005; De Bellis, 2001; Maheu, et al., 2010; McCrory, et al., 2011, 2012; Parker & Nelson, 2005; Pollak, et al., 2001; Pollak & Tolley-Schell, 2003; Rao, et al., 2010; Teicher et al., 2003; Tottenham, et al., 2011). However, whether neural markers of developmental processes associated with less extreme childhood environments remain relatively unknown. The evidence regarding neurodevelopmental processes, associated with emotional development, and the parent-infant relationship in typically developing families is very limited. Given that half a century's worth of research has concentrated on the enduring effects of the early parent-infant relationship, it is notable that little is known about the underlying brain processes that give rise to cross-sectional and longitudinal connections between caregiving and child behaviour. As such, this thesis aimed to make a contribution to bridging the gap in this literature by looking at the association between several aspects of the early-parent infant relationship and markers of functional brain development. In particular, this thesis focused on emotional face-processing as a domain of neural development that may be especially relevant to social and emotional development.

Through a series of studies presented in this thesis, it was possible to explore a range of factors associated with the early parent-infant relationship in relation to an infant's neural processing of emotion. Specifically, four main influential factors were assessed: 1) infant temperament measured using a self-report questionnaire; 2) parental mental health, in particular parental depression, anxiety and parenting stress; 3) parental sensitivity as measured by direct observation of free-play interaction and finally; 4) infant attachment classification, again measured directly by a standardised assessment procedure – The Strange Situation. All four factors were assessed in relation to infants' neurological processing of emotional faces using Electroencephalography (EEG), specifically looking at infant Event-Related Potentials (EPRs) known to be relevant in emotion processing.

This thesis has contributed in several ways to how we might understand the association between the early parent-infant relationships and infants' neural processing of emotion in non-clinical populations:

1) The data presented in this thesis has provided evidence to show that early parent-infant relationships in 'typically' developing families are linked to infants' neural mechanisms related to emotion processing. Specifically, this research has shown that in the context of sensitive and responsive caregiving, infants' neural responsitivity to positive emotions is higher, possibly reflecting an increased salience of positive social cues.

2) The data presented in this thesis found evidence for infants in a low-risk community sample whose parent has relatively elevated mental health symptoms, specifically symptoms of depression and anxiety, showing a neural sensitivity centred again on the processing of positive emotion cues.

3) Finally, the data presented is the first to investigate the role of attachment in infant's brain responses to face stimuli, and indicated that infant attachment security may be unrelated to infants' neural responses to emotion processing, at least with respect to facial emotion cues and indices measures at the level of ERPs.

The focus of this chapter is to first summarise the main findings from each chapter presented in this thesis. This will then be followed by a discussion of the theoretical and clinical implications arising from this research. Finally, the limitations of the research presented in this thesis will be discussed alongside suggestions for future research.

7.2 Summary of Results:

7.2.1 Infant Temperament:

Consistent with earlier infant ERP studies, in this study of 7-month old infants, the infant emotion sensitive ERP component known as the negative central (Nc), was significantly larger in amplitude to negative emotion – specifically fearful faces – than to positive or neutral facial expressions. The early face sensitive N290 ERP component and the later P400 ERP component were not modulated by emotional expressions.

Infant temperament, as measured concurrently using a parent-report questionnaire at 7 months, was found to be associated with differences in the neural processing of facial emotion cues. Specifically, one subscale of the questionnaire relating to self-regulation, '*soothability*' was shown to be related to increase amplitudes to fearful facial expressions for both the Nc and the P400 ERP components. Infants' who had lower scores for '*soothability*' had larger neural amplitudes to fearful faces (relative to neutral faces) for both the Nc and P400. Furthermore, infants who were considered difficult to soothe, displayed smaller amplitudes to fearful faces (relative to neutral) on an early face processing ERP component, the N290.

The remaining composite subscale, *Negative Emotionality and/or reactivity* did not relate to infants' ERP amplitudes to emotional facial expressions.

7.2.2 Maternal Mental Health:

Self-reported levels of depressive symptoms were significantly related to infants neural processing of emotional expressions. Specifically, parents who reported low levels of depression in turn had infants with higher amplitudes at the Nc ERP component to positive - happy - facial expressions over the left hemisphere and greater amplitudes to neutral facial expressions over the right hemisphere. The Nc was not associated with self-reported levels of anxiety or parental stress in this study.

The early face sensitive component the N290 was seen to be modulated by reported levels of parental anxiety. Specifically infants' whose parent (mother) reported high levels of anxiety had statistically significant increased amplitudes to positive emotion. Self-reported depression levels and parental stress did not effect infants' N290 ERP amplitudes in relation to emotion processing.

The later infant ERP component the P400 was not modulated by parental reports of depression, anxiety or stress in relation to emotion.

7.2.3 Parental Sensitivity:

Parental sensitivity, as assessed through direct observation of free-play interaction, was found to be associated with differences in infants' neural responses to emotional expressions. Specifically, parents who scored higher on a composite score of parental sensitivity, comprising of; sensitivity, low intrusiveness, high structuring and low hostility, had infants who exhibited larger neural amplitudes to positive – happy – facial expressions on the emotion sensitive infant ERP component the Nc. This effect was unrelated to infant temperamental traits.

Parental sensitivity did not relate to infants' ERP responses to emotion for either the N290 nor the P400 ERP components.

7.2.4 Infant Attachment status:

Infant attachment status, as measured by the Strange Situation, was found to be unrelated to the neural processing of emotion at an ERP level. Contrary to predictions, the Nc amplitude was not greater to fearful faces for securely attached infants compared to insecurely attached infants. Given the association between attachment and maternal sensitivity, we tested whether the previously-reported association between maternal sensitivity and infant's neural responses to happy faces held up after attachment had been controlled. The sensitivity effect became marginally significant ($p = 0.06$) suggesting some overlapping variance between the two that is linked to the Nc response to positive emotion. However, given the absence of an effect of attachment and the marginal significance of the sensitivity effect, it is within good reason to assume that the sensitivity effect is largely independent of attachment.

The infant N290 and P400 ERP components were unrelated to infant attachment classification in regards to emotion processing.

7.3 Theoretical Implications:

The development of the neural systems underlying infants' emotion processing has received scant attention in relation to the environments they experience with their primary caregivers in typical developing families. This thesis has provided some valuable data on this relatively new area of research and the findings may be relevant to our theoretical understanding of how the early parent-infant relationship shapes the neural processes involved in emotional development.

One of the striking findings from this study was the apparent importance of infants' processing of *positive* emotional expressions. Specifically, two different factors linked to the parent-infant relationship were found to be associated with infants' neural processing of *positive* emotion but not negative emotion. First, sensitive and responsive caregiving on the part of the parent correlated with their infant's increased neural responses (in the Nc) to positive (happy) facial expressions, but was uncorrelated with their neural responses to fearful expressions. Similarly, low levels of maternal depressive symptoms were associated with increased neural amplitudes to positive facial expressions at the Nc over the left hemisphere. Interesting, subsequent analysis with the smaller sample in this study showed that the maternal sensitivity effect remained when controlling for maternal depression, suggesting that these two associations are possibly independent of each other. Of course, it should also be noted that these two features of the caregiving environment are likely to be related. There is clear evidence that shows an association between maternal depression and parenting behaviour, specifically that high levels of maternal depressive symptoms are correlated with increased levels of insensitive caregiving (Goodman & Brumley, 1990; Lovejoy, et al., 2000). As such, it can be suggested that both measures are indexing related aspects of sensitive parenting behaviour. Given the Nc's sensitivity to salient information, the result appears to suggest that for infants who experience highly positive parenting, positive emotion expressions are encoded as particularly salient.

This tendency to encode positive emotion as more salient can be interpreted in two ways. First, it might be assumed that infants who experience highly sensitive and responsive care are in fact exposed to more positive emotion in everyday interactions with their caregiver. There is good reason to assume this, given Mary Ainsworth's original theoretical concept of maternal sensitivity and its relationship to positive affect (Ainsworth 1969). In this interpretation, it is the familiarity of such faces that is potentially driving the infants' neural responses to positive expressions. As previously mentioned, the Nc has been documented, particularly in the first few years of life, to be sensitive to familiar stimuli, specifically more sensitive to the mother's face than a stranger's, and to familiar objects (De Haan & Nelson, 1997, 1999; Nelson, et al., 2000). Given this understanding of the Nc, it is plausible that familiarity of positive emotion for those infants experiencing sensitive caregiving is leading to greater neural resources when processing happy faces. Furthermore, there is evidence that suggests infants who have a parent with depression are exposed to higher levels of withdrawn parenting that can be marked with flat affect and a lack of expressiveness (Cohn, et al., 1990; Goodman & Brumley, 1990; Lovejoy, 1991; Lovejoy, et al., 2000). In this regard, those infants who have parents who report low levels of depressive symptoms are very likely to experience positive facial expressions more than infants with parents who report higher levels of depression.

Outside of infancy research there is evidence that suggests that expressed emotion is contagious to the receiver (emotional contagion Hatfield, Cacioppo, & Rapson, 1994; Pugh, 2001; Rapson, et al., 1993). Research into mimicry has substantiated this point, showing that through mimicry an observer creates an emotional experience that is the mirror image of the emotion of the expresser (Hatfield, et al., 1994; Hatfield, Carpenter, & Rapson, 2014). Mimicry, as in the imitation of others expressions, is considered to play a crucial role in the understanding and interpretation of emotions in others (A. Atkinson & Adolphs, 2005; Niedenthal, et al., 2001; Oberman, et al., 2007). It can happen both in and outside of conscious awareness (Dimberg, Thunberg, & Grunedal, 2002; Sonnby–Borgström, 2002) and can be overtly visible as well as covertly invisible (Tassinary, 2007; Tassinary & Cacioppo, 1992). Interestingly, it has been shown that when individuals are made to mimic happy emotion (a smile) there are greater physiological rewards (Kraft & Pressman, 2012). It is interesting to hypothesize that infants who experience sensitive caregiving and in turn are exposed to more positive facial expressions during interactions mimic these emotions more, which leads to greater physiological and ultimately psychological reward. As such, it could be that positive emotion becomes more salient in terms of its biological payback and this is reflected in infants, who are exposed to more happy facial expressions through higher sensitive caregiving, allocating more neural resources to process positive emotion. In that sense, one might expect that the infant is, or becomes, an active player in responding to and sustaining positively valenced reciprocal social interactions, of which these neural changes play a key part. Although these interpretations of the way in which parental sensitivity impacts infants' neural processing of emotion are intriguing, they are nonetheless speculative and clearly it is not possible on the basis of the current evidence to infer a causal link. In particular, an infant's direct exposure to specific emotional faces was not assessed in the current research and as such infants' exposure to positive emotion in relation to sensitive caregiving remains unsubstantiated.

An alternative, although not unrelated, interpretation of these findings is to suggest that the association arises not because infants have been exposed to more positive emotional expressions, but rather that infants who experience a harmonious caregiving environment may come to perceive positive emotion as an external cue that is predictive of positive social exchange. This is highly probable given that parental expressed positivity is associated with parental warmth, responsivity and synchrony (Darling & Steinberg, 1993; Zhou, et al., 2002). Thus in our research, positive facial cues may signal to the infant that a rewarding social encounter is about to begin and as such greater attention is allocated to this external cue in preparation and/or anticipation to a positive encounter. This line of thinking is particularly intriguing given the ecological thinking relating an individual's expressed emotions to their intentional actions (Buck, 1984; Darwin, Adler, & Hutchins, 1872). Specifically, expressed positivity and in particular an individual's smile signify a desire and readiness to interact in a pleasant encounter (Campos, Mumme, Kermoian, & Campos, 1994; Manstead, Fischer, & Jakobs, 1999; Messinger, 2002). In addition, decades of research into social learning have drawn attention to the importance of positive emotion in promoting infants' social engagement (Feinman & Lewis, 1983; Seidel, et al., 2010; Sorce, et al., 1985). Parental sensitivity and, in turn, parental positive affect, provides a further reward in the form of effective affect regulation for the infant (Braungart-Rieker, Garwood, Powers, & Wang, 2001). It is interesting to speculate that those infants who experience higher displays of sensitive caregiving may be relating the processing of positive emotion in association with the eventual feeling of emotion equilibrium. As such, when these infants are exposed to positive emotion, more attentional resources are dedicated to processing it due to its possible biological and psychological benefits. Explicitly testing the role of positive emotion as a reward signal in infants would be extremely interesting in that regard and one might predict that infants who have experienced more sensitive and response care would assign greater reward value to positive emotions and possibly learn reward cue-outcome associations faster. This research also provides a platform for future research to explore related biological systems in the processing of emotion to individual differences in the early shared environment, such as pupillometry, and heart rate, which are useful indicators of relevant parameters like attention and salience.

The neural generators thought responsible for the Nc have been localised to the anterior cingulate cortex (ACC) in the prefrontal area (Reynolds & Richards, 2005). The indentified link between the ACC and its crucial role in attention regulation (Bush, Luu, & Posner, 2000) strengthens the localisation of the Nc to the ACC. In relation to emotion processing, evidence from adult studies has shown coactivation of both the amygdala and the anterior cingulate cortex (ACC) during the processing of emotional faces (Morris et al., 1998; Vuilleumier, Armony, Driver, & Dolan, 2001). It has been argued that the amygdala may be a key neural structure in not only associating affective significance to environmental stimuli but also producing adaptive responses, such as increased perceptual functioning (Vuilleumier, 2005). The amygdala's role in mediating threat-related information is firmly established (Davis, 1990, 1992; Mahan & Ressler, 2012; Maren, 2001; Pape & Pare, 2010), however there is growing evidence for the amygdala's role in other affective functions in relation to positive emotion (Canli, Sivers, Whitfield, Gotlib, & Gabrieli, 2002; Hamann, Ely, Grafton, & Kilts, 1999;

Johnsrude, Owen, White, Zhao, & Bohbot, 2000). Although comparisons to infant amygdala involvement in the processing of emotional faces are not possible, primarily due to the feasibility of functional neuroimaging techniques with young infants, one can speculate that it is possible that similar subcortical regions are being employed, especially given the evidence linking the neural origins of the infant Nc to the ACC (Reynolds & Richards, 2005) and the adult evidence showing coaviation of the ACC and the amygdala during emotion processing (Morris, et al., 1998; Vuilleumier, et al., 2001).

The further related finding to infants' neural processing of positive emotion was seen in chapter 4, where infants with a parent with high anxiety symptoms displayed an increased neural sensitivity to positive faces at the early face-sensitive component the N290. This finding is particularly intriguing given the discussion above in relation to high sensitive caregiving correlating to an increased neural sensitivity to positive emotion at the later ERP component the Nc. A very clear and plausible explanation to the anxiety related finding can be attributed to the infants' exposure, and thus familiarity, to specific emotional expressions. The infant ERP component the N290 has empirically been identified as 'face sensitive' (De Haan, et al., 2002; Halit, et al., 2003) and is largely considered to be the developmental precursor to the adult 'face-sensitive' ERP component the N170 (De Haan, et al., 2002; Halit, et al., 2004; Halit, et al., 2003). Specifically, the N290 mirrors the adult N170 in polarity and face stimulus response (Bentin, et al., 1996; Itier & Taylor, 2004; Rossion, et al., 1999; Taylor, et al., 1999). Furthermore, there is some, although limited, evidence that suggests the N290 ERP component might be sensitive to novel stimuli (Righi, et al., 2014). As such, one could argue that this increased neural sensitivity to positive emotion at the N290 for infants with a parent with high anxiety traits, is due to the fact that they are less familiar with the structural features of positive emotional faces. It could be theorised that these infants are less exposed to positive emotion in their everyday interactions with their caregiver and as such require more neural resources to encode its structural features. Again, although exposure to specific emotional expressions was not quantified in this research, there is evidence that suggests that anxious mothers display less warmth and positivity compared to control mothers when interacting with their children (Whaley, et al., 1999). A similar line of interpretation could be made in reference to the results reported in chapter 3, in which infants who were rated as temperamentally easier to soothe displayed a similar N290 neural response but to negative emotion. If increased amplitudes at the N290 is reflecting a lack of familiarity in the structural features of an unfamiliar face, infants who were regarded as easier to soothe may not be as familiar with the structural features of a fearful faces as much as those who are harder to soothe.

It is important here to consider that it is possible that the effect in relation to the N290 may in fact be due to the familiarity of facial features rather than the unfamiliarity as previously described. This is probable as there is evidence to indicate that the infant N290 amplitudes can be larger for familiar faces (Righi, et al., 2014; Scott, et al., 2006). Thus, the results regarding parental anxiety and infants' early N290 response to positive emotion could occur because these infants have had *more*, not less, exposure to positive faces. Given that there is some evidence to suggest that anxious individuals display more non-genuine smiles (Harrigan & Taing, 1997; Heerey & Kring, 2007), this suggestion of familiarisation at the N290 is an interesting consideration. Once again, quantifying direct exposure to facial expressions would help differentiate this effect.

This thesis is not the first to report individual differences in modulating the N290's response to emotionally presented stimuli. A very recent study by Jessen and Grossman (2015) showed that infants who were reported as having low levels of perceptual sensitivity by their parents, had increased neural amplitudes to positive emotion facial expressions on the N290. Perceptual sensitivity and its association with anxiety have long been debated and there is both some theoretical (Easterbrook, 1959) and empirical (Zaffy & Bruning, 1966) evidence that has suggested that individuals with high anxiety traits are less sensitive to perceptual input. Given the increased occurrence of childhood anxiety amongst those with parents experiencing anxiety (Beidel & Turner, 1997; Capps, et al., 1996; Whaley, et al., 1999), it is interesting to hypothesize that perhaps for the infants in this study who experienced a parent with high levels of anxiety, they themselves are more anxious, whether this is through a genetic contribution or via the environment. Certainly, this is a general problem that the current thesis cannot address – namely that parent-to-infant associations may reflect shared genetic tendencies, rather than a process of environmental transmission from the parent to the infant's neural development. Taking Jessen and Grossmann as an example, it is possible that the infants of anxious parents are also less perceptually sensitive due to common temperamental tendencies they share with their parent. Although Jessen and Grossman (2015) do not offer an explanation as to why happy faces elicited larger neural responses at the N290 in those with low perceptual sensitivity, one could also argue that anxiety related behaviours in the infant, stemming from their early relationship with their parents, may play a role. It must be noted that infants' level of perceptual sensitivity was not assessed in the current research so it was not possible to address this directly. Future studies could benefit from including parental anxiety and infant's level of perceptual sensitivity in regards to infants' ERPs to emotional faces.

Finally, the neural sources thought responsible for the infant N290 have been localized to the superior temporal sulcus and the fusifrom gyrus (Johnson, et al., 2005). These identified neural sources are consistent with the adult findings for the N170(Itier & Taylor, 2002, 2004). In regards to anxiety, a very interesting recent fMRI study has shown abnormalities in children's fusiform gyrus in relation to parental anxiety (Buss, Davis, Muftuler, Head, & Sandman, 2010). Given this understanding that the origins of the N290 may stem from activity in the fusiform gyrus (Johnson, et al., 2005), the findings in this study in relation to parental anxiety and infants' N290 ERP responses are particularly interesting.

To conclude, the research presented in this thesis has attempted to advance our understanding of the role of early parent-infant interactions in infant neural development, focusing particularly on the neural systems that are linked to facial-emotion processing. The study reported herein provided evidence that in non-clinical populations, positive emotion may be particularly sensitive to environmental influence, and that parental mental health and sensitive caregiving may be important features of the environment for future research to focus on.

It is important to discuss the lack of a finding in relation to infants' neural correlates of emotion processing and attachment. Attachment theorists have provided the developmental field with a wealth of data that suggests a moderately strong relationship between early attachment patterns and social and emotional processing (for a review see Dykas & Cassidy, 2011), as well as social competence more generally (Groh, et al., 2014). However, despite this impressive field, there are only two studies that have associated attachment patterns specifically to the processing of emotional facial expressions, only one of which assessed this in infants under the age of one and neither of which involved neuroimaging or electrophysiology (Peltola, et al., 2015; Steele, et al., 2008). Based on the studies by Steele and Peltola it seemed reasonable to assume that attachment classification may be associated with differences in neural responses relate to emotion processing. The study reported in this thesis did not find an association with infant attachment patterns and neural correlates relating to emotion processing using ERP methodology. Although these results were somewhat surprising, particularly given the findings by Peltola et al. (2015) in which attachment classification was associated with attentional bias towards emotional faces in a similar age, the findings are none the less explicable.

Clearly the distribution of attachment patterns in this sample is of particular relevance when considering this null finding. A relatively skewed distribution, with secure infants representing 71% of the sample, would have impacted negatively on the statistical power of this study, and this is arguably one of the strongest explanations for the lack of a significant finding. However, given that there are only two studies to date that have investigated attachment patterns directly in relation to infants processing of emotional expressions in non-clinical populations, the lack of findings in the current study might also cast some doubt on the role of attachment in infant emotion processing.

Indeed, the evidence relating early attachment to infants' emotion processing abilities is not particularly uniform. For example, Peltola and colleagues found that secure attachment was associated with fewer attentional shifts away from fearful faces, a result which the authors interpreted as an indicator of typical development; i.e., the typical bias infants show towards threat-related information (De Haan & Nelson, 1999; Kotsoni, et al., 2001; Nelson, 1993; Nelson & Dolgin, 1985). In addition, the level of disorganised behaviours observed in the Strange Situation was correlated with greater attentional shifts away from fearful faces, suggesting a lack of an attentional bias to fearful faces (Peltola, et al., 2015). However, these findings by Peltola et al. appear to contradict the observational and neural evidence that has shown that within clinical populations, which have higher rates of insecure attachment (Cicchetti, et al., 2006; Cyr, et al., 2010), there is an increased sensitivity towards threat-related information (Cicchetti & Curtis, 2005; Parker & Nelson, 2005; Pollak & Kistler, 2002; Pollak, et al., 2001; Pollak & Tolley-Schell, 2003; Shackman, et al., 2007; Tottenham, et al., 2011). Direct observations of attachment were not assessed in these clinical populations, but the contradictory associations across these research studies may well suggest that the relationship between adverse early parent-child experiences, including insecure attachment, and emotion processing may be complex.

Another interpretation of the null finding for attachment is that it reflects ambiguity or inconsistency in exposure to specific faces within the caregiving environment. The weak association between attachment and caregiver sensitivity implies that there is much that is not understood regarding the interactional patterns most closely linked to attachment security and insecurity. Therefore, we lack a good understanding of the kinds of exposures of relevance to infant emotion processing that might be linked with attachment. The problem in a sense reflects the fact that, unlike sensitivity, attachment is not a measure of the environment per se, but rather a developmental outcome of the environment. Thus, the occurrence of particular emotional expressions on the part of the caregiver is less certain in relation to attachment than it is to sensitivity, where emotional expression is one of its defining characteristics. As such, to the extent that infant ERP responses to emotional faces reflect exposure, the connection with attachment is much less certain and therefore more likely to be weak, absent or variable.

7.4 Clinical Implications

This research has highlighted that variations in sensitive parenting and maternal mental health are associated with differences in infants' neural functioning in relation to the processing of emotional face stimuli. The consequences of these findings for social and emotional development are potentially significant. Although the downstream effects of the observed neural differences into observable behaviour are unclear, the data presented in this thesis may provide some useful insights into novel ways of approaching clinical practice with young infants and parents. The clinical implications of the research presented in this thesis primarily relate to promoting sensitive parenting and to the importance of early indicators of maternal mental health problems.

It has been robustly documented that the parent-infant relationship has a substantial and lasting effect on an individual's life trajectory (Bokhorst, et al., 2003; Bowlby, 1958, 1982; Bretherton & Munholland, 2008; Lyons-Ruth & Jacobvitz, 2008; Schore, 1997, 2001, 2002; Siegel, 2001; Strathearn, et al., 2009; Swain, et al., 2007) . Specifically, impairments in the domains of social and emotional development have been extensively evaluated with respect to the quality of experiences an infant has with their caregiver (Belsky & Fearon, 2002; Kertz, et al., 2008; Mäntymaa, et al., 2004; NICHD Early Child Care Research Network, 1999; Sroufe, 2005; Zhou, et al., 2002). Collectively, a child's early parenting experiences, relate to a host of later emotional outcomes for the child. Sensitive care and secure attachment have been found to forecast greater understanding of emotion (Denham, et al., 2002; Greig & Howe, 2001; Laible & Thompson, 1998; Ontai & Thompson, 2002; Raikes & Thompson, 2006; Rosnay & Harris, 2002; Steele, et al., 1999), better emotion regulation (Braungart & Stifter, 1991; Bridges & Grolnick, 1995; Cassidy, 1994; Diener, et al., 2002; Leerkes & Wong, 2012; S. Waters, et al., 2010) and greater social skills (Bost, et al., 1998; Groh, et al., 2014; Grossmann & Grossmann, 1991; Lewis & Feiring, 1989; Sagi-Schwartz & Aviezer, 2005; Schneider, et al., 2001; Verschueren & Marcoen, 1999) in later development.

When considering the findings reported in this thesis, it is evidently important to establish how these different neural processes cascade down into observable behaviours in current and later development. As noted earlier, it is certainly plausible given the significance of facial emotion expression for social interaction that these effects may bias social development in important ways. For example, infants who experience highly positive and sensitive parenting appear more sensitive to encoding this social information, possibly making them more oriented towards social interactions, which in turn may facilitate more rapidly and efficient social learning. Sensitive caregiving, via its effects on the infant's neural sensitivity to emotional cues, may in effect be equipping the infant with the mental tools necessary for receiving and promoting rewarding social interactions. If, on the other hand, infants who experience less sensitive care do not encode positive emotions to the same degree, it may place these infants at a disadvantage in similar social encounters, and limit their social learning.

The ability to accurately identify, discriminate and process an emotional face is a social capacity that is essential not only for interacting with others, but specifically allows one to predict behaviour (Muir & Hains, 1993; Phillips, Wellman, & Spelke, 2002) and guides reciprocal behaviour (Feinman & Lewis, 1983; Fox, 1994b; Marsh, Ambady, & Kleck, 2005; Winkielman, Berridge, & Wilbarger, 2005). The significant neural differences recorded in this thesis among those infants who experience different early caregiving environments, either directly through insensitive caregiving or indirectly by varying degrees of maternal mental health problems, provide an important marker that may highlight potential difficulties in this core social capacity. There is evidence to suggest that individuals who have an inability to recognise and discriminate facial displays of affect are more likely to experience mental health problems, placing themselves at greater risk for social isolation and exclusion. This is evident in both children (Blair, 2006; Marsh & Blair, 2008; Sinzig, et al., 2008) and adults (Blair, 2006; Dolan & Fullam, 2006; Norton, et al., 2009). Although not comparable in terms of the clinical nature of the studies mentioned above and the current research presented in this thesis, it is interesting to speculate that the early caregiving relationship may play an important role in the development of emotion identification and recognition and that this might be identifiable early in development.

The importance of this early relationship and, in particular, the knowledge that sensitive caregiving facilitates positive developmental outcomes for the child, has resulted in a multitude of intervention studies designed to increase sensitive caregiving in order to promote positive child outcomes (for a review see van IJzendoorn, Juffer, & Duyvesteyn, 1995). One interesting potential implication of the current findings is that neural markers might provide new insights regarding the most important intervention elements that impact on child outcomes. For example, the findings reported here suggest that focusing on how parents use emotional cues to encourage the infant's social interaction may be particularly important. For example, helping parents to link together sequences of interactions in which the infant is able to notice a positive expression, and experience this predictably leading to rewarding social interaction may encourage the infant to encode positive expressions as highly salient and promote social development. In general, one could imagine in the long-run that EEG techniques could be used to create sensitive biomarkers of treatment, by providing objective indication that treatment is having an impact before proceeding with large-scale longitudinal follow-up studies.

7.5 Limitations and Future Research:

Collectively, the series of studies presented in this thesis constitute a novel addition to the literature examining the developmental consequences of the early parent-infant relationships. However, the research reported throughout is not without its limitations.

Firstly, the sample used throughout this thesis was obtained from a wider database of parents who had volunteered for developmental research in the local area – North

West London. Recruitment for this database involved visiting children's centres, play groups, libraries and baby clinics. Every effort was made to include less affluent areas in an attempt to recruit a demographically diverse database of parents. However, despite this effort, parents who agreed to take part in the developmental research did so on a voluntary basis, with the majority of those volunteering having a particular interest in child development. This resulted in a sample that was restricted to an advantaged middle-class population. A key goal of this research was to examine the effects of parenting within the normative range on infant brain development, the restricted range of circumstances included in the sample meant that the findings were not representative of typical parenting in the population. This limitation is particularly evident in chapter 6 in regards to attachment distribution. The global distribution sets secure dyads at 62 % (van IJzendoorn, et al., 1999) whereas secure attachment classifications represented 71% of our sample. Furthermore, chapters 4, 5 and 6 incorporated a sample in which 83 -88% were educated to university level. Given the Office for National Statistics reports UK global rate to be 38% (Office for National Statistics 2013), this is a stark contrast. This sample bias restricts the interpretations that can be drawn from the results and as such caution must be exercised when generalising the findings to a wider demographic. As such, the results should be viewed as preliminary, with replication being paramount. Future research would benefit greatly by investigating more 'at risk' populations that fall outside of clinical boundaries but represent a broader cross-section of parenting across a range of circumstances and communities.

Secondly, a methodological limitation referred to repeatedly in this thesis is the lack of information regarding infants' direct exposure to emotional facial expressions. The self-reported measures assessing mental health were selected for their validity and reliability at capturing current mental health difficulties. They are cost-effective and time-effective measures that indirectly provide an insight into the environment experienced by infants. More directly, observing free-play interaction between parent and infant and employing a well-validated protocol and coding scheme, furthered this understanding of the caregiving environment. However, neither method directly captures the exposure the infant has to particular facial expressions. Quantifying the exposure an infant has to particular facial expressions would prove invaluable. Although it is possible to speculate about an infants' exposure to facial displays of affect, particularly given our understanding that infants are exposed to more positive emotions in the first half of the first year (Malatesta & Haviland, 1982) as well as the evidence suggesting parents with increased depressed mood reflect more negative facial expression (Field, 1984), empirical tests of these hypotheses would be important in future research. Investigations that assess an infant's direct exposure to facial displays of affect alongside other elements of parenting would prove beneficial.

Thirdly, the focus of this research was centred around the second half of the child's first year and it examined concurrent, or relatively close to concurrent associations. In the future, it would be extremely valuable to incorporate the methods used in this study into a longer-term follow-up study, to test the role of neural processes in mediating the effects of caregiving on later socio-emotional outcomes. Furthermore, it would also be extremely valuable to assess parenting repeatedly across the early years in relation to a child's neural development, so that changes in emotion related processes could be examined over time. Given the correlational nature of this thesis, investigations that incorporate interventions that are designed to address maternal mental health issues and caregiving behaviour would provide much needed casual evidence regarding the findings in this thesis.

7.6 Summary

This thesis has yielded evidence that the early parent-infant relationship among non-clinical families is related to infants' neural processing of emotion. Identifying a neural marker in association with the early caregiving environment has been the focus of much clinical research; however, in typically developing families this association has been substantially overlooked. Furthermore, thus far no studies have examined the early parent-infant relationship in relation to infant neural correlates of emotion. This thesis provided important initial evidence to fill this gap in the literature. The data presented in the course of this thesis suggests that infants in the first year of life, who experience a caregiving environment that is sensitive and responsive to their needs, develop a heightened neural sensitivity to displays of positive emotion. This sensitivity was indexed by increased ERP amplitudes at an empirically identified emotion sensitive infant ERP component, the Negative Central (Nc). This pattern of association was evident both when assessing free play parent-infant interactions and self-reported levels of maternal depression. It was argued that these infants may be encoding positive emotion as an indicator of social reward, which may promote social engagement. This thesis also demonstrated that an early face-sensitive ERP component, the N290, appears to be sensitive to individual differences in maternal anxiety as well as temperamental differences in infants' self-regulatory behaviours. Finally, the data presented in this thesis in relation to infants' attachment security appears to suggest that attachment classification is unrelated to infants' neural processing of emotion at the level of ERPs. How these neural differences then translate into observable behaviour both concurrently and in later development remains unknown and is an important area for future research.

8 Appendices

8.1 Appendix 1: Participant Information Sheet and Informed Consent Form

Anna Freud Centre

Caring
for young
minds

Baby Lab

Understanding how the early parent-infant relationship affects infants' ability to process emotional expression

Anna Freud Centre London

Prof Peter Fonagy
The Anna Freud Centre
University College London

Dr Pasco Fearon
The Anna Freud Centre
University of Reading

Samantha Taylor-Colls
The Anna Freud Centre
University College London

Lara Platten
The Anna Freud Centre
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12 Maresfield Gardens
London
NW3 5SU

We would like to invite you to participate in this research project. You should only participate if you want to; choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, it is important for you to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or you would like more information.

The aim of this study is to investigate if the early parent-infant relationship may affect an infant's ability to process emotion. In particular, how infants interact socially towards their parents in different situations and whether different types of parent-infant relationships alter the way infants process emotions.

The study will involve two visits to our 'baby lab' at the Anna Freud Centre. At the first visit, when your baby is 7 months old we will show your baby a series of pictures with individuals displaying different types of expressions. During this we will record tiny changes in the electrical activity of your baby's brain using sensors on your baby's scalp. The sensor net does not produce any electricity, it only measures the electrical impulses your baby's brain naturally creates. The procedure is non-invasive and won't harm your baby in any way. The sensor net is made up of tiny spongy pads that require no gel when applying. For your baby it will be the same feeling as wearing a hat. Before we apply the net we soak it in some warm water that has a teaspoon of baby shampoo and salt in it, it is this that allows a good contact between your baby's scalp and the net. Your baby will be wearing the sensor net for no longer than 10 minutes. During the same visit we will also measure your baby's behaviour to a range of situations, for example how they respond to a puppet game or an unpredictable mechanical toy. We will videotape these situations so we can review them afterwards. We will then ask you to interact with your baby in a small number of situations, such as playing with toys and changing a nappy. Again, we will videotape these situations so that we can look at parents' approach to the role of parenting and how infants respond to this. You will be with your baby at all times and are free to comfort them as needed.

Four months later we will ask you to return to the baby lab so that we can observe how your infant responds to new toys, meeting new people and being separated from you for two short periods of time. This will help us to see whether there are relationships between how infants respond to emotional expressions and how infants behave with their parents in several common situations. If your baby becomes distressed we will terminate the procedure immediately. This event is very similar to when you and your baby may visit a doctor and therefore if your baby is upset during the event there may be a small chance they will be upset shortly after. During the same visit we will record you interacting with your baby for 6 minutes as we did previously during the 7mth visit. This will allow us to see how your baby approaches the role of play over time. All video footage will be destroyed three years after the write up of the study.

During the 7 month visit, with your permission, we would like to collect a DNA sample from your baby. We would like to do this as we are particularly interested in individual differences in infants' emotional temperament. We will thus look at a small number of genes that may be involved in children's emotional and the

(continued overleaf)

Understanding how the early parent-infant relationship affects infants' ability to process emotional expression

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DNA collected will not indicate any medical problems. The procedure will involve using a cotton bud to gently brush the inside of your baby's cheek (we will ask you to do this for us). The cotton bud will then be placed in a sterile solution container for analysis. All data will be anonymous and all biological material will be destroyed after the genetic information has been analysed. This is not a medical diagnostic test and will not need to be mentioned on medical insurance applications.

Before each visit we will send out a couple of questionnaires that we will ask you to bring with you when you visit the lab. You will be with or be able to see your baby at all times.

None of the experiments will involve risk of any harm or discomfort to infants or parents. In return participants will receive a £5 book voucher and have travel expenses reimbursed.

It is up to you to decide whether or not to take part. If you choose not to participate it will involve no penalty to which you are otherwise entitled. If you decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason.

All data will be collected and stored in accordance with the Data Protection Act 1998.
If you have any questions about this research please contact Dr. Pasco Fearon on 02074432208. This study has been approved by the UCL Research Ethics Committee

Anna Freud Centre

Caring for young minds

Baby Lab

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Parents' Consent

I ……………………………………………………………………
agree that I have

? read the information sheet and/or the project has been explained to me orally;
? had the opportunity to ask questions and discuss the study;
? received satisfactory answers to all my questions or have been advised of an individual to contact for answers to pertinent questions about the research.
? I understand that both my child's and my participation will be taped/ video recorded and I am aware that the videos will be kept for a remainder of three years on the completion of the research and then destroyed.
? I am aware that the video material will be viewed and analyzed only by those directly involved with the research.
? I agree for the video material with my baby to be used for teaching professionals about baby development and behaviour (optional). ? If I agree to this I am aware that you will contact me nearer the time to confirm my consent.
? I do/do not (please circle) give consent for genes to be collected.

I understand that I am free to withdraw from the study without penalty if I so wish and I consent to the processing of my personal information for the purposes of this study only and that it will not be used for any other purpose. I understand that such information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998.

Signed:……………………………………Date:……………………….

Investigators Statement:

I ……………………………………………………
confirm that I have carefully explained the purpose of the study to the participant and outlined any reasonably foreseeable risks or benefits (where applicable).

Signed:……………………………………Date:……………………….

8.2 Appendix 2: Babylab Flyer

Anna Freud Centre

Caring for young minds

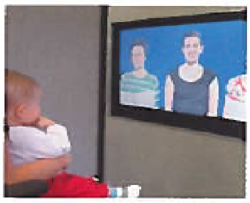
Baby Lab

Ethically Approved By

UCL

Ever wondered what your baby is thinking?

How do they understand you and the world around them?



Babies up to 18 months needed for fun, interesting research into social and emotional development

We are always happy to hear from new and expectant parents!

Volunteers receive travel expenses plus a book token for their baby

Anna Freud Centre

Baby Lab

Ethically Approved By

UCL

To register
Call: 020 7443 2208/38
Email: Samantha.taylor-colls@annafreud.org
Lara.platten-brown@annafreud.org
or visit: www.annafreud.org/infantlab
www.surveymonkey.com/s/babylab

Our friendly lab is based at:
The Anna Freud Centre
12 Maresfield Gardens
London
NW3 5SU

Complete and return -
Your Name:

Baby's Name:

Date of Birth:

Male/Female:

Telephone:

Email:

Baby Lab
The Anna Freud Centre
Freepost LON12033
London
NW3 4YS

8.3 Appendix 3: Ethical Clearance

UCL RESEARCH ETHICS COMMITTEE
GRADUATE SCHOOL OFFICE

UCL

Dr Pasco Fearon
The Anna Freud centre
UCL
21 Maresfield Gardens
London
NW3 5SD

02 December 2008

Dear Dr Fearon

<u>Notification of Ethical Approval</u>
<u>Ethics Application: 1598/001: Understanding how the early parent-infant relationship affects infants' ability to process emotional expression</u>

Further to receipt of your satisfactorily amended information sheet and consent form, I am pleased to confirm that your application has been approved by the UCL Research Ethics Committee for a period of 12 months from the commencement of the project, i.e. 1st December 2008.

Approval is subject to the following conditions:

1. It is a requirement of the Committee that research projects which have received ethical approval are monitored annually. Therefore, you must complete and return our 'Annual Continuing Review Approval Form' PRIOR to the **1st December 2009**. If your project has ceased or was never initiated, it is still important that you complete the form so that we can ensure that our records are updated accordingly.

2. You must seek Chair's approval for proposed amendments to the research for which this approval has been given. Ethical approval is specific to this project and must not be treated as applicable to research of a similar nature. Each research project is reviewed separately and if there are significant changes to the research protocol you should seek confirmation of continued ethical approval by completing the 'Amendment Approval Request Form'.

The forms identified above can be accessed by logging on to the ethics website homepage: http://www.grad.ucl.ac.uk/ethics/ and clicking on the button marked 'Key Responsibilities of the Researcher Following Approval'.

3. It is your responsibility to report to the Committee any unanticipated problems or adverse events involving risks to participants or others. Both non-serious and serious adverse events must be reported.

   <u>Reporting Non-Serious Adverse Events</u>.
   For non-serious adverse events you will need to inform Ms Helen Dougal, Ethics Committee Administrator (h.dougal@ucl.ac.uk), within ten days of an adverse incident occurring and provide a full written report that should include any amendments to the participant information sheet and study protocol. The Chair or Vice-Chair of the Ethics Committee will confirm that the incident is non-serious and report to the Committee at the next meeting. The final view of the Committee will be communicated to you.

Reporting Serious Adverse Events

The Ethics Committee should be notified of all serious adverse events via the Ethics Committee Administrator immediately the incident occurs. Where the adverse incident is unexpected and serious, the Chair or Vice-Chair will decide whether the study should be terminated pending the opinion of an independent expert. The adverse event will be considered at the next Committee meeting and a decision will be made on the need to change the information leaflet and/or study protocol.

On completion of the research you must submit a brief report (a maximum of two sides of A4) of your findings/concluding comments to the Committee, which includes in particular issues relating to the ethical implications of the research.

Yours sincerely

Sir John Birch
Chair of the UCL Research Ethics Committee

Cc: Samantha Taylor & Lara Platten, The Anna Freud Centre, UCL

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