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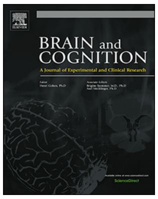

The neural correlates of attachment security in typically developing children

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ABSTRACT

This study investigated neural correlates of children's attachment security using functional magnetic resonance imaging. Fifty-one boys' attachment styles (age mean = 9.5 years, SD = 0.61) were assessed with the Separation Anxiety Test (SAT). We created an fMRI version of the SAT to activate children's attachment system in fMRI environment and contrasted two conditions in which children were instructed to infer the specific feeling of the boy in the picture or to identify objects or physical activities. In the final fMRI analysis (N = 21), attachment security could be detected at the neural level corresponding to the behavioural differences in the attachment interview. Securely attached children showed greater activation in the frontal, limbic and basal ganglia area which included the dorsolateral prefrontal cortex, amygdala, cingulate cortex and striatum, compared to other children who had lower quality of attachment. These regions have a key role in socio-emotional information processing and also represent a brain network related to approach and avoidance motivation in humans. Especially the striatum, strongly linked to reward processing underpinning social approach and avoidance motivation, showed the largest effects in these differences and also positively correlated with emotional openness scores in SAT. This suggests that the quality of attachment configures the approach and avoidance motivational system in our brain mediated by the striatum.

1. Introduction

1.1. Attachment security

Attachment is a deep and strong emotional bond that connects an infant to a caregiver at an early stage of life and it is characterized by specific approach behaviours in children to seek proximity with the attachment figure, especially when upset or threatened (Ainsworth, 1973; Bowlby, 1969). It is almost universal that infants develop attachment relationships, but there are individual differences in how effectively the infants and children can use their caregivers as a source of comfort in the face of danger or threats from the environment and how balanced they are between exploration and seeking proximity to the caregiver in various situations. Attachment security, that refers to these individual differences in the quality of the attachment relationship, is well-established at a behavioural level and has been classically divided into two categories: "secure" and "insecure" attachment relationships (Ainsworth et al., 2015; Bowlby, 1973). Secure attachment indicates that children rely on the caregiver's availability as a source of comfort and protection when they feel unsettled or fearful of something in the environment, while those with insecure attachment have not experienced consistent availability from their caregivers and become anxious, expressing fear or anger that their caregivers are not responsive when needed (Ainsworth et al., 2015). Insecure attachment style can take the form of anxious attachment and avoidant attachment (Ainsworth et al., 2015). Attachment anxiety is predicted by the receipt of unreliable or unpredictable caregiving, whereas experiences of rejection by caregivers predict the development of an avoidant attachment style. Individuals high in avoidant attachment style dismiss the importance of attachment bonds, while anxiously attached individuals are hypervigilant for signs of social rejection, and readily admit their longing for improved attachment relationships. Over time, each group tends to develop a diverse and mixed set of profiles, but a number of longitudinal studies on attachment have shown that these differences in attachment security are stable across the life span from infancy to adulthood (Waters, Merrick, Treboux, Crowell, & Albersheim, 2000)

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and even extend across generations (Benoit & Parker, 1994).

One reason that attachment security has a prolonged effect on an individual's life is that attachment is basically supported by a physiological system that is biologically predisposed and selected during evolution for survival (Bowlby, 1969, 1982). The attachment behavioural system can be viewed as a physiological adaptation and homeostasis, such that attachment security can be understood as a result of adapting the attachment behavioural system to the caregiving environment. A second reason that attachment security is stable over time is that from interactions with primary caregivers, children develop mental representations of the self and others, called "internal working models", which are internalized in one's mind and utilized as a source of how to react to socio-emotional cues in close relationships and more generalized social contexts (Bretherton & Munholland, 2008). However, the neural substrates underlying this stable attachment security remain largely unknown.

1.2. *The neural basis of attachment security*

There is growing empirical evidence that individual differences in attachment security are associated with different neurobiological functions in the processing of perceptual information (Cohen & Shaver, 2004; Mikulincer & Shaver, 2007), especially in emotional information. Regions in prefrontal, limbic and basal ganglia are thought to be responsible for individual differences in attachment security. However, the amygdalae also are often related to attachment security. During processing various emotional information such as social feedback in gaming situations (Vrticka, Lordier, Bediou, & Sander, 2014), emotional faces (Norman, Lawrence, Iles, Benattayallah, & Karl, 2014; Redlich et al., 2015; Vrticka, Andersson, Grandjean, Sander, & Vuilleumier, 2008), attachment-related stress (Lemche et al., 2006; Liu, Ding, Lu, & Chen, 2017), emotional adjectives (Debbané et al., 2017), emotional regulation (Moutsiana et al., 2014), or mother's face (Tottenham, Shapiro, Telzer, & Humphreys, 2012), amygdalae showed different patterns of activity in individuals with different attachment styles. These results suggested that the different sensitivity for emotional cues may be modulated by attachment security in the amygdalae.

The basal ganglia serve a wide range of functions, including motor, cognitive, motivational, and emotional processes (Arsalidou, Duerden, & Taylor, 2013). Consistent with this broad-reaching involvement in brain function, basal ganglia dysfunction has been implicated in numerous neurological and psychiatric disorders. Recent research revealed a critical role for brain reward systems, involving the basal ganglia, in the biological underpinnings of attachment security, as neural responses to facial expression (Donges et al., 2012; Vrticka et al., 2008), reward processing (Takiguchi et al., 2015), or the perception of mother's face (Minagawa-Kawai et al., 2008). There is mounting evidence for a role of reward circuits and reinforcing processes in social approach and bonding in maternal and romantic love (Aron et al., 2005; Fisher, Aron, & Brown, 2005; Lenzi et al., 2008; Nitschke et al., 2004; Ranote et al., 2004; Sander, Frome, & Scheich, 2007).

Most of research on the neural basis of attachment security, however, has studied adult populations, although attachment security is formed at an early stage of life. Investigating the neural underpinnings of attachment security in childhood would allow us to determine if the adult model applies to younger cohorts, as well as determining possible developmental differences in this complex social behaviour. Furthermore, most research has used relatively generalized emotional stimuli such as facial expressions to examine functional regions related to attachment security, but attachment security is classically assessed by activating one's attachment system through presenting negative attachment-related stimuli, such as strange situations in infancy and separation pictures in childhood and adolescence. This leaves open the question of whether or not the differences in brain activity during processing facial expressions would reflect the neural basis of attachment security, or would be simply distinct neural responses to facial expression in individuals who have a different styles of attachment.

One research group studied the attachment system specifically in the fMRI environment, to examine the functional neuroanatomy of attachment security. Buchheim et al. (2006) used attachment-related scenes to activate the attachment system in adult patients with borderline personality disorder (BPD). The BPD patients showed significantly more anterior midcingulate cortex activity in response to pictures which depicted characters facing attachment threats alone and their unresolved attachment was associated with increasing amygdala activation (Buchheim et al., 2006). Here we employed this paradigm with healthy children to determine the functional neuroanatomy of attachment security and to investigate differences in brain activity in children with different levels of attachment security.

2. Material and methods

2.1. *Participants*

Fifty-one boys were recruited from elementary schools (age mean = 9.5 years, SD = 0.61). After receiving informed consent, trained examiners visited their home and assessed attachment security using the Separation Anxiety Test (SAT; Hansburg, 1972; Resnick, 1993). The SAT is a semi-projective interview using separation pictures to assess attachment from preschool-aged children to adolescents. All interviews were audiotaped, transcribed verbatim, and coded according to the SAT manual (Resnick, 1993). The SAT rating scales include nine subscales (e.g., Emotional openness, Devaluing of attachment, Self-blame, Resistance/Withholding, Preoccupied anger, Displacement of feelings, Anxiety, Coherence of transcript, Solutions), and assign each child to one of the attachment classifications based on the profile in each subscale (e.g., Secure, Insecure_avoidant, Insecure_preoccupied). As a result, twenty-nine boys (56.9%) were classified as secure attachment and twenty-two boys (43.1%) were classified as insecure attachment. Secure attachment is prevalent in diverse populations and children in this group show a diverse set of profiles that are considered more qualitative rather than quantitative (Diamond & Marrone, 2003). Based on the SAT coding system, only fourteen boys in secure group could be assigned into the prototypical "securely attached" category with very high scores for emotional openness compared to the others in secure group who revealed restricted feelings. Insecure attachment is represented by two distinct patterns, avoidant or ambivalent type. In our study, nineteen out of twenty-two in the insecure group showed avoidant attachment style. All subjects who declined the brain scan or had a history of psychiatric or neurological illness, left handedness, or metal in their body were excluded. Additionally, eight subjects were also excluded from more than 4 mm head motion during the scan. Finally, 21 boys were included: seven boys were in the prototypical securely attached group, another seven were securely attached but restricted in expressing feelings and seven boys were in the insecurely attached group, six of whom had avoidant attachment type. Demographic information is presented in Table 1. Parents' educational level and social economic status were similar across all participants. All parents reported that the main caregiver of the child during the first three years was the mother. This study was approved by the institutional review board for human subjects at the Seoul National University. All children and their parents provided written informed consent prior to study entry.

2.2. *Stimulus materials and procedure*

We constructed an fMRI version of the SAT to activate children's attachment system and to elicit mental engagement with attachment-related experiences in the MRI environment. The stimulus material consisted of attachment-related pictures which originally came from other versions of SAT, the Adult Attachment Projective Picture System (AAP), or neuroimaging studies that measured neural response of the