Maternal Anxious Attachment Style is Associated with Reduced Mother-Child Brain-to-Brain Synchrony

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Synchrony in developmental science reflects the coordination of mother and child to one another's mental states. Mentalisation processes are influenced by individual attachment styles. A mother with an anxious attachment pattern tends to be hypervigilant to cues of rejection and likely to rely on her child's facial expressions to interpret his/her mental states. We hypothesised that anxiously attached mothers are less able to attune to their child's emotional state during an everyday joint activity, a state reflected in reduced brain-to-brain synchrony. To test this hypothesis, we profiled mothers' Need for Approval (NfA), an index of attachment, and used functional Near-infrared Spectroscopy (fNIRS) hyperscanning with 31 mother-child dyads to measure prefrontal cortex (PFC) brain-to-brain synchrony while mother-child dyads watched three 1-min animation videos together. Greater maternal NfA is associated with less synchrony in the frontal left and medial left prefrontal clusters, which map to the left lateral PFC. This area of the brain is implicated in mentalisation. Anxiously attached mothers appear to exhibit less brain-to-brain synchrony with their child which indicates less attunement to his/her mental state, potentially undermining the quality of their shared experiences during everyday joint activities.

Keywords: attachment, mother-child, synchrony , parenting, NIRS, prefrontal cortex

Introduction

Attachment is the stability with which individuals cultivate proximity with relational figures in their lives (Sperling & Berman, 1994). In adulthood, these attachment figures may originate from various relationship partners, including romantic partners, friends and family members. Profiles of adult attachment are broadly classified into secure and insecure (anxious or avoidant) styles (see Mikulincer & Shaver, 2010, for an overview). Individuals with secure adult attachment employ security-based strategies to regulate their emotions. For instance, during threat appraisal, secure individuals associate thoughts of proximity, support and comfort with their attachment figures. By contrast, threat appraisal triggers maladaptive notions of attachment in insecurely attached individuals. While persons with avoidant attachment may repress proximity-seeking thoughts, those with anxious attachment may activate thoughts of proximity along with fears of rejection. As a result, individuals with anxious attachment tend to be hypervigilant toward social cues that signal rejection (Bartholomew, 1990; Bartholomew & Horowitz, 1991; Griffin & Bartholomew, 1994; Mikulincer & Shaver, 2010).

For a mother, an insecure attachment representation may manifest as difficulties in regulating her emotional state to respond synchronously to the needs of her child. Synchrony refers to reciprocal patterns of responses between dyadic partners that reflect attunement to one another's mental states (Fleming et al., 1999; Feldman, 2012). In a mother-child dyad, synchrony may be undermined by maternal attachment insecurity. For instance, mothers with insecure attachment have a greater tendency of being insensitive (Jones et al., 2018; van IJzendoorn, 1995) and emotionally unavailable (Licata et al., 2016). In turn, parenting sensitivity can be traced to variation in maternal brain activation patterns. For example, Atzil et al. (2011) found that synchronous mothers, who coordinate their responses to match their child, showed activation in reward-related networks, whereas intrusive mothers, who do not adjust to their child's emotions, showed activation of stress-related pathways. Taken together, these findings point to tangible links between maternal attachment styles and synchronous or asynchronous parenting that may be rooted in maternal brain responses.

Azhari et al. (2019) previously examined mother-child brain-to-brain synchrony in relation to parenting stress using tandem functional near-

infrared spectroscopy (fNIRS). fNIRS records changes in local blood oxygenation such that higher levels of oxygenated blood serve as a proxy of brain activation. Greater parenting stress was associated with diminished synchrony in the dyad's medial left cluster of the prefrontal cortex (PFC) when the pair engaged in an everyday activity of watching animation videos together. The PFC is associated with mentalisation and other social cognitive processes. On this basis, we reckoned that mothers with more parenting stress experienced greater difficulty when regulating their emotions to match their mental state to that of their child.

The present study extends (Azhari et al., 2019) and aims to investigate the influence of maternal attachment style on mother-child brain-to-brain synchrony. Because brain-to-brain synchrony is believed to reflect matching mental states between members of the dyad (Azhari et al., 2019; Feldman, 2012), there is reason to believe that mother-child brain-to-brain synchrony might vary as a function of maternal attachment style. According to a model by Fonagy & Luyten, (2009), mentalisation can be distinguished into two processes that are adopted differentially based on adult attachment style: one is emotional and the other is cognitive mentalisation. Emotional mentalisation emphasises automatic and implicit processing of others' emotions based on some concrete physical attributes, such as facial expressions. In contrast, cognitive mentalisation involves voluntary and conscious processing of other's emotions by inferring some internal attributes, such as feelings and intentions (Fonagy & Luyten, 2009; Lieberman, 2007). Mentalisation is mediated by an extensive brain network, including the lateral PFC (Fonagy & Luyten, 2009). Individual attachment styles may influence cognitive and emotional mentalisation strategies. For instance, an anxious attachment style promotes hypervigilance to signals of social rejection, thereby enhancing emotional mentalisation (Fonagy & Luyten, 2009). In line with this model, engaging in a joint activity that reduces access to her child's facial expressions would render mothers' mentalisation more difficult for anxiously-attached mothers whose strategy is to rely on concrete social cues. Consequently, our first hypothesis is that dyads with anxiously attached mothers exhibit reduced brain-to-brain synchrony as mothers face greater difficulty matching to their child's emotional state. Our second hypothesis is that, similar to Azhari et al. (2019), reduced synchrony would be observed in the medial left cluster. This cluster falls within the lateral PFC, an area which underlies cognitive mentalisation processes that is

postulated to be more effortful for anxiously attached mothers (Fonagy & Luyten, 2009; Lieberman, 2007).

Methods

Participants

In total, 34 mother-child dyads (14 girls) (Mean age of mothers=34.7 years, S.D.= 4.1 years; Mean age of children=41.9 months, S.D.= 6.1 months) participated. Participants were recruited through online platforms (forums and Facebook groups) before they were screened for cognitive, visual, hearing, or developmental impairments that might hinder them from comprehending the task stimuli. Participants signed Informed consents, and each dyad received monetary compensation upon completion of the study. This study was approved by the Institutional Review Board of Nanyang Technological University.

Experimental Procedure

Mothers first completed an attachment style questionnaire. Then, mothers' and children's brain responses were investigated using tandem functional near-infrared spectroscopy (fNIRS) while they watched three animation videos. All videos were presented on a laptop approximately 40 cm in front of the dyad who were alone in the test room (Figure 1 from Azhari et al. 2019).

Questionnaire

The Attachment Style Questionnaire (ASQ; Feeney et al., 2014) is a 40-item instrument that measures an adult's attachment style in regard to general (rather than specific romantic) relationships. The questionnaire employs a 6-point Lickert scale on which participants rate themselves and others. Items are grouped into five subscales: *Confidence, Discomfort with closeness, Relationships as secondary, Need for approval,* and *Preoccupation with relationships.* These subscales are grounded in classification theories of attachment styles, where *Need for approval* and *Preoccupation with relationships* indicate anxious attachment and *Discomfort with closeness* and *Relationships as secondary* reflect avoidant attachment (Stein et al., 2002). *Confidence* is related to secure attachment. Our main interest and hypotheses concerned scales having to do with anxious attachment, so we used the ASQ to derive anxious attachment status in mothers.

Video Stimulus

Participants were presented with three 1-min video clips that were excerpted from The Incredibles, Peppa Pig, and Brave. To increase the generalisability of the dyadic activity across different animation shows, the clips differed in emotional valences and visual and audio

complexities. A 5-sec fixation cross appeared before the onset of the first clip, after which a 10-sec fixation cross appeared between each clip (Figure 2 from Azhari et al. (2019). The clips were presented in a semi-randomised manner on a 15-inch Acer Laptop. Both brightness and volume were set to 60%.

The visual complexity of each clip was quantified using Python and FFmpeg (v. 3.4.4). To analyse audio complexity, each video was first converted to an audio file on FFmpeg. Praat software (v. 6.0.46) was then used to extract audio intensity and fundamentals from the audio files. To compute the emotional valence of each clip, two independent coders rated each sec of the clip as either positive, neutral, or negative. The sum of the sec-by-sec coding across the entire clip was used to rate positivity. Table 1 shows the results of visual and audio complexities and emotional valences of each clip.

Functional Near-Infrared Spectroscopy (fNIRS)

fNIRS Data Acquisition and Pre-Processing

fNIRS recording was conducted in tandem hyperscanning mode at a scan rate of 7.81Hz (NIRSport, NIRx Medical Technologies LLC). 8 LED sources (wavelengths of 760nm and 850nm) and 7 detectors were arranged on the caps according to a standard PFC montage to form 20 channels on each cap (NIRS v.205 software). Distances between source and detector pairs were under an optimal maximum of 3 cm.

fNIRS pre-processing was done on the NIRSLab software (NIRS v.205 software). Markers that denote the onset of each video stimulus were added to the time series signals. Upon visual inspection of the signal, discontinuities and spike artefacts were manually removed. The 20 channels were then inspected for their gain and coefficient of variation (CV) scores which indicated the noise level in the signal. Channels with a gain>8 and CV>7.5 were deemed to have significant noise and subsequently discarded. A band-pass filter of 0.01-0.2 Hz was applied on the remaining channels to eliminate baseline shift variations and slow signals. To compute hemoglobin levels for each channel, pre-processed signals were converted to changes in concentration of oxygenated (HbO) and deoxygenated hemoglobin (HbR) as a function of the modified Beer-Lambert law. The resulting haemodynamic signals were examined by two independent coders to inspect for any further artifacts.

Cluster Grouping of Channels

As proximal regions of the PFC function in an interdependent manner, examining prefrontal responses in clusters rather than single channels lends a practical interpretation of the findings. Similar to Azhari et al. (2019), the channels were divided into four groups based on their physical proximity to each other to form the frontal left, frontal right, medial left, and medial right clusters as reported in Table 2. The corresponding Brodmann areas for each cluster are depicted in Figure 3.

Dynamic Time Warping (DTW) Analyses

Dynamic Time Warping (DTW) algorithm from the dtw package (Giorgino, 2009) in R studio (version 1.0.153, R-core 3.4.2). was used to compute the distance between the time series signals of a mother and child in each channel (Senin, 2008). The distance index of channels that belong to the same cluster were averaged to generate a mean distance index for each cluster. The greater the distance score computed by DTW, the lower the synchrony exhibited by the dyad in that cluster (Giorgino, 2009). DTW enables similar but out-of-phase shapes within the same time window to match (Keogh & Ratanamahatana, 2005), leading to an optimised alignment of any two time series sequences (Senin, 2008). Normalised distance indexes were used so that the indexes ranged from 0 to 1. We used DTW analysis previously (Azhari et al., 2019), and it has also been used widely in the extant literature (Tuzcu & Nas, 2005; Rath & Manmatha, 2003; Myers & Rabiner, 1981; Rabiner et al., 1978) (See *Supplementary Materials* for additional analyses.

Analytic Plan: Synchrony Analyses

Preliminary Analyses

The distance indexes of channels that belong to the same cluster were averaged across all channels in that cluster, which generated a distance index for each of the four clusters. In a preliminary analysis, positivity ratings of the video, child gender, and maternal age were included in a regression model against each of the cluster's distance index. Video complexity and audio fundamental scores were fitted as covariates in the models.

Descriptive Analyses

The mean and standard deviation of distance index values for each of the four clusters are reported.

Inferential Analyses

To test the first hypothesis that dyads with anxiously attached mothers would exhibit less

synchrony, we analysed the association between each of the 5 attachment sub-scales with the distance index. These analyses were run for each cluster to test the second hypothesis, that reduced synchrony would be observed in the medial left cluster. Multiple linear regression models were run for each factor, with video complexity and audio fundamental scores as controls. For example, when investigating Need for Approval in the frontal right cluster, the model would be: Distance Index (frontal right cluster) = Need for Approval + (Video Complexity + Audio Fundamentals). False Discovery Rate (FDR) correction was applied. Significant results between any of the attachment factors and the distance index would denote that synchrony in a specific cluster was predicted by maternal attachment style.

Results

Synchrony Analyses

Preliminary Results

No significant finding emerged between distance index and child gender, maternal age, and video positivity ratings.

Descriptive Results

The means and standard deviations of distance index values for each of the 4 clusters are reported in Table 2.

Inferential Results

No significant results emerged for 4 attachment sub-scales of the ASQ in any cluster (see *Supplementary Materials*). Only *Need for Approval*, which reflects maternal attachment anxiety showed significant results. Controlling for video complexity and audio fundamentals, *Need for Approval* was significantly associated with the distance index in the frontal left (R^2=0.0196, F(3, 220)=2.491, p<.05) and medial left (R^2=0.0318, F(3, 229)=4.301, p<0.01) clusters. These clusters are chiefly mapped to the left lateral PFC which is an extensive region composed of parts or the entirety of the left Brodmann Areas (BA) 8, 9, 10, 45 and 46.

Our first hypothesis, that dyads with maternal anxious attachment would show diminished synchrony, was supported. *Need for Approval* had medium to strong effect size positive relations with the distance index in both the left frontal (r=0.41, p=0.025) (Figure 4) and left medial (r= 0.46. p = 0.019) (Figure 5) clusters. Greater distance index scores reflect diminished brain-to-brain synchrony between mother and child.

However, our second hypothesis, that the reduced synchrony would emerge in the left medial cluster, was supported but also extended,

as *Need for Approval* had a moderate negative correlation with synchrony in both the frontal left and medial left clusters. The distance index in the frontal right (R^2=-0.007, F(3, 225)=0.469, p>0.05) and medial right (R^2= 0.0142, F(3, 255)=2.239, p>0.05) clusters were not significantly associated with *Need for Approval*.

Discussion

This study aimed to investigate whether maternal anxious attachment style is associated with mother-child brain-to-brain synchrony when dyads engage in an everyday joint activity of watching animation shows together. We embarked on this study with two hypotheses. First, we hypothesised that dyads with anxiously attached mothers would show less brain-to-brain synchrony. This hypothesis was fulfilled as dyads of mothers with higher *Need for approval*, reflecting adult attachment anxiety (Stein et al., 2002), exhibited less brain synchrony. Second, we predicted that diminished synchrony would be observed in the left medial cluster of the prefrontal cortex (PFC). This hypothesis was fulfilled as reduced synchrony occurred in the left medial cluster of the PFC, which points to a left lateralised effect of maternal attachment anxiety on brain-to-brain synchrony. We also found reduced synchrony in the frontal left cluster.

Need for approval was associated with reduced synchrony, but no significant effect emerged for *Preoccupation with relationships*, a subscale that also measures attachment anxiety. As these scales reflect attachment in adult relationships (Feeney et al., 1994), different findings between the two subscales could emerge in a parenting relationship. Persons with high *Need for approval* worry that they are not liked by others and do not meet others' expectations. In a parenting relationship, a mother with high *Need for approval* might fear not being liked by her child and not fulfilling the expectations of being a mother. A mother with high *Preoccupation with relationships* would be apprehensive of relationships for fear of abandonment. However, in a parenting relationship, it is unlikely that a mother is concerned with being deserted by her young child. As our study involved mother-child dyads, so it is reasonable that we only observed a significant effect with the *Need for approval* subscale of anxious attachment.

Reduced synchrony was particularly observed in the frontal left and medial left clusters, which overlap with the left lateral PFC where cognitive mentalisation processes occur. Mothers with attachment anxiety predominantly engage in emotional mentalisation, comprising of automatic processes that rely on visible social

cues (e.g., facial expressions) to form an understanding of the mental state of others (Fonagy & Luyten, 2009). However, as the child sat on the mother's lap during our study, opportunities to monitor such cues were minimised. To compensate for the lack of concrete social cues from their child, anxiously attached mothers might have experienced greater recruitment of the lateral PFC to engage in cognitive mentalisation strategies (e.g. interpreting the intentions of others). Cognitive mentalisation is subserved by an extensive network of brain regions spanning the prefrontal and temporal regions (Fonagy & Luyten, 2009; Lieberman, 2007). The lateral PFC, composed of BA8, BA9, BA45, and BA46, is implicated in several stages of perceptual processing, all of which moderate mentalisation (Barbas & Zikopoulos, 2007; Medalla et al., 2007). Corroborating these findings, we observed that the higher the mothers scored on an anxious attachment scale, the less the brain-to-brain synchrony in the lateral PFC. Moreover, the notable lateralisation of this effect is potentially due to predominantly left hemisphere processes responsible for active behavioural control (Amodio, 2010; Amodio et al., 2007). Interconnected via the fronto-striatal–pallidal circuit, the left PFC is extensively associated with brain regions involved with goal-directed responses (Fuster, 2001; Passingham, 1993). For instance, both primary and supplementary motor cortices engage with the left PFC via this circuit to support behavioural regulation (Aron, 2007). Along these lines, an anxiously attached mother might have required greater recruitment of the left lateral PFC in an attempt to mentalise and control her behaviours to match that of her child, which ultimately reduced synchrony in the left lateral PFC.

This study had several limitations. Two are especially noteworthy. First, the scope of our investigation was limited to the prefrontal cortex. Several other regions of the brain which are connected to the lateral PFC might have exhibited similar patterns of synchrony in association with attachment anxiety. Future studies should extend the region of investigation to capture changes in synchrony in other areas of the brain that are implicated in mentalisation, including the subcortical structures like the basal ganglia and amygdala, and cortical areas such as the lateral temporal cortex (Fonagy and Luyten 2009; Lieberman 2007; Satpute and Lieberman 2006). Second, our study only measured state anxiety in the context of attachment. Maternal trait anxiety could have also contributed to measured

synchrony and should be investigated in future studies.

Conclusion

Our study revealed that dyads with anxiously attached mothers exhibit less brain-to-brain synchrony in the left lateral PFC when the pair engages in a typical joint activity. As this region is implicated in mentalisation, our findings suggest that everyday activities which reduce access to the child's concrete social cues might hinder the anxiously attached mother from mentalising and matching her emotional state to that of her child.

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Data Availability

The dataset for this publication can be found in the Data Repository of the Nanyang Technological University (DR-NTU Data): https://doi.org/10.21979/N9/PC6PZD

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Table 1. Video complexity, audio fundamentals, audio intensity, and positivity ratings of the three video stimuli excerpted from Brave, Peppa Pig, and The Incredibles.

Video Stimulus	Video Complexity (bytes)	Audio Fundamentals (Hz)	Audio Intensity (W/m^2)	Positivity Ratings
Brave	658119.31	245.26	59.89	45
Peppa Pig	468369.81	218.37	62.50	59
The Incredibles	423005.66	271.64	56.30	-54

Table 2. Distance indexes in the four PFC clusters, along with the channels found in each cluster and corresponding sample size and demographic information.

Cluster	Channels	Brain Areas	Brodmann Areas	N	Mother's age	Child's age	Child's gender (male, female)	Mean Distance Indexes	Standard Deviation
Frontal left	4, 6, 7, 11	Anterior PFC, Middle frontal gyrus, Pars orbitalis of Inferior frontal cortex (IFC)	BA47L, BA10L, BA46L	31	35.2 ±4.3	41.6 ± 6.1	18, 13	0.0002079219	0.0002316823

Frontal right	13, 14, 16, 19	Anterior PFC, Middle frontal gyrus, Pars orbitalis of Inferior frontal cortex (IFC)	BA10R, BA46R, BA47R	30	35.2 ± 4.3	41.7 ± 6.1	18, 12	0.0002082626	0.0001932817
Medial left	1, 2, 3, 5, 8	Dorsolateral PFC (DLPFC), Lateral PFC, Broca's area of IFC, Lateral DLPFC, Superior frontal gyrus	BA46L, BA45L, BA09L, BA08L	27	35.4 ± 4.5	41.1 ± 5.4	15, 12	0.0003006815	0.0003597335

Medial right	10, 15, 17, 18, 20	DLPFC, Superior frontal gyrus, Lateral DLPFC, Lateral PFC, Intermediate frontal cortex, Pars triangularis of IFC	BA08R, BA09R, BA46R, BA45R	29	35.3 +/ 4.3	41.2 +/ 5.7	16, 13	0.0002573503	0.0002298021

Figure 1. Experimental arrangement during the fNIRS session.

Figure 2. Diagram depicting the stimuli presentation. A fixation cross was screened for 5 sec before the onset of the first clip. A total of three 1-min video clips were presented with an inter-stimulus interval of 10 sec between each clip.

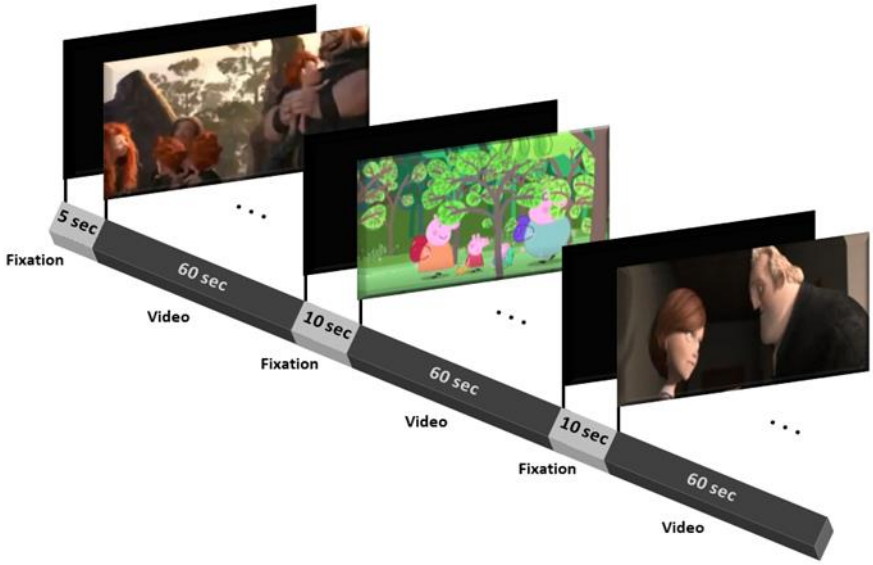

Figure 3. Positions of the 20 channels according to a standard prefrontal cortex montage. Note: SFG = superior frontal gyrus, MFG = middle frontal gyrus, IFG = inferior frontal gyrus, aPFC = anterior prefrontal cortex.

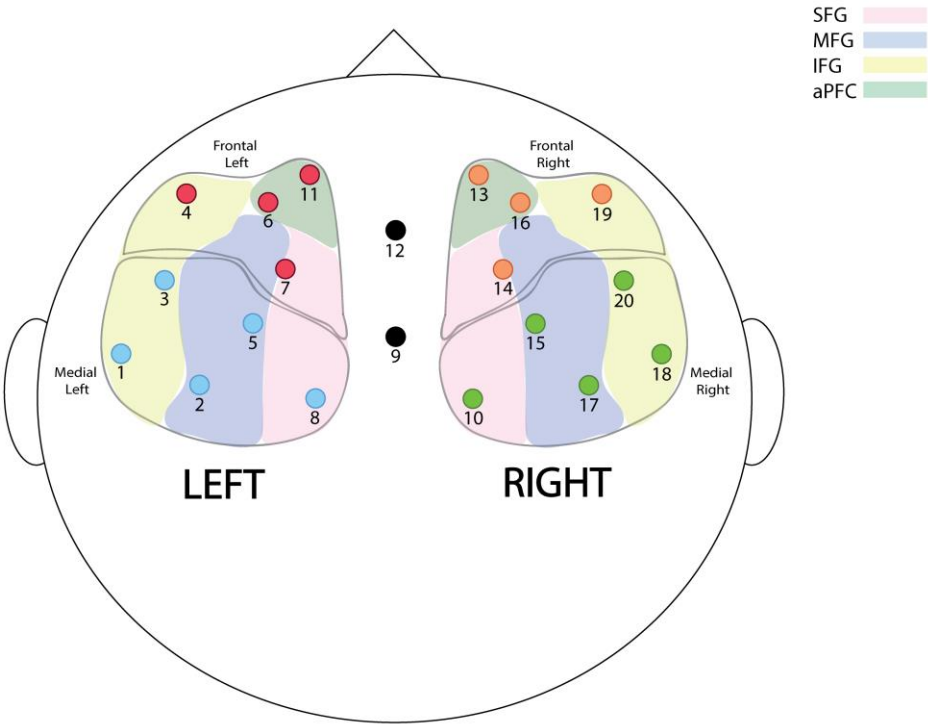

Figure 4. Correlation between *Need for Approval* and normalised distance index between mother and child in the left frontal cluster of the prefrontal cortex.

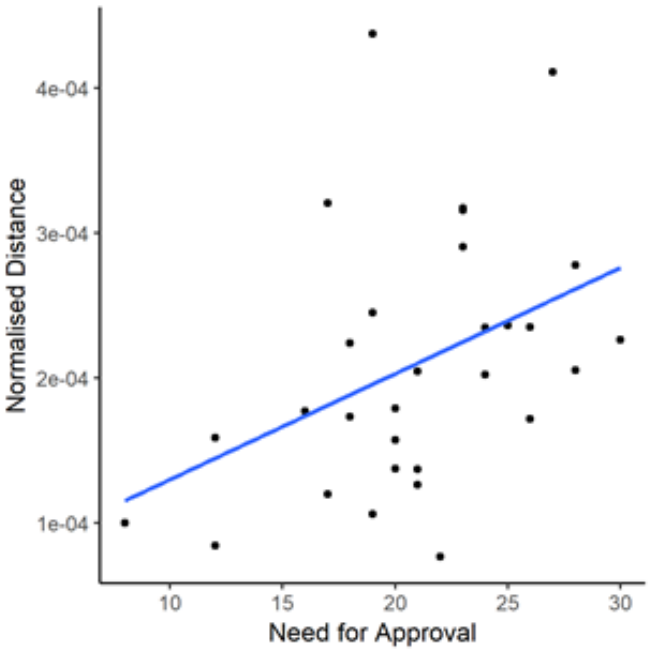
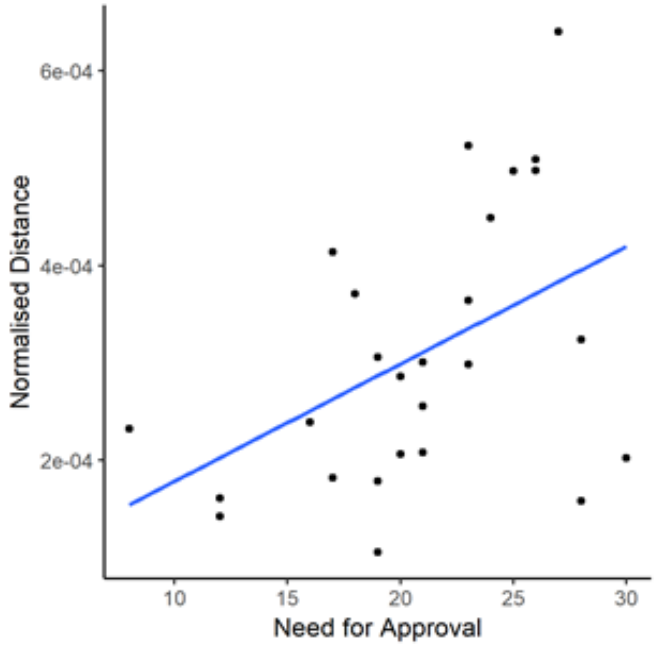
Figure 5. Correlation between *Need for Approval* and normalised distance index between mother and child in the left medial cluster of the prefrontal cortex.