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ARTICLE



Neural signatures of chronic accessibility in parent – adult child attachment bonds

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ABSTRACT

Some of the closest reciprocal relationships are between parents and their children. As part of the attachment characterizing many parent-child bonds, individuals form mental representations that are chronically accessible and calibrate expectations for future relationships. We predict that there exist unique neural signatures of this chronic accessibility. Young ($N = 29$, 16 females) and older adults ($N = 27$, 12 females) made trait judgments for parent or child, respectively, during fMRI scanning. Multivariate analysis identified whole-brain patterns of activation that covaried with the magnitude of parent-child attachment when thinking about that individual. Higher levels of parent and child attachment were associated with lower neural recruitment in anterior cingulate cortex, amygdala, posterior cingulate cortex, medial temporal lobe, and occipital face area. Results provide novel evidence for neural signatures of chronic accessibility, as bringing to mind one's attached parent or child requires less engagement of brain regions involved in distress relief, memory, and facial processing.

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Attachment; parent-child relationships; mental representations; chronic accessibility; fMRI

Introduction

Our most critical bonds are often formed with our parents and children. These stable relationships, often conceptualized as attachment bonds, are characterized by feelings of security with affect-regulatory benefits (Hazan, Gur-Yaish, & Campa, 2004; Pietromonaco, Feldman Barrett, & Powers, 2006; Sroufe & Waters, 1977). Ethological attachment is theorized to necessitate proximity maintenance to caregivers, promoting chances of infant survival (Bowlby, 1982). Early observational studies of toddlers demonstrated parental attachment figures' role in soothing separation-related distress upon reunion (Ainsworth, Blehar, Waters, & Wall, 1978), and recent work highlights parents' neurobiological response to their children's distress (Noriuchi, Kikuchi, & Senoo, 2008; Swain et al., 2014). The parent-child attachment bond is uniquely reciprocal, consistently demonstrating biobehavioral synchrony, or the sensitization to and coordination of physiological and behavioral responses (Feldman, 2012). Moreover, this relationship is capable of persisting as both child and parent age and adapt to shifts in behavioral dynamics related to role-reversal (Ainsworth, 1989; Carpenter, 2001).

Inherent to parent-child attachment bonds are the mental representations, or internal working models, of these

figures that come about due to reward conditioning. Lack of perceived proximity to an attachment figure engages the mental representation of that figure, providing comfort and security. Importantly, attachment figure mental representations exhibit chronic accessibility (Andersen & Cole, 1990; Baldwin, Keelan, Fehr, Enns, & Koh-Rangarajoo, 1996); they are easy to bring to mind and readily available for utilization in the face of stressors, requiring fewer cognitive resources overall. Because of the powerful reciprocal roles of parental and adult child attachment figures, it is likely that their chronically accessible mental representations have unique neural signatures.

Limited existing work examines patterns of neural activity underlying mentalizing for, or imagining the thoughts and feelings of, these attachment figures. Mothers viewing photos of their own child versus an unfamiliar child, recruit insula, amygdala, anterior paracingulate cortex, and superior temporal sulcus; mothers viewing an unfamiliar child versus their own show increased activity in regions related to attention, including intraparietal sulcus and precuneus, and face perception, such as fusiform gyrus (Leibenluft, Gobbin, Harrison, & Haxby, 2004). The default network is an ensemble of functionally-connected brain regions including medial prefrontal and posterior cingulate cortex, inferior parietal

lobule, lateral and medial temporal lobe, and inferior frontal gyrus (Andrews-Hanna, Smallwood, & Spreng, 2014). This network has been implicated in self-related processes such as autobiographical recollection, in addition to social cognitive reasoning (Andrews-Hanna et al., 2014). Personal judgments about close friends reliably recruit the default network (Krienen, Tu, & Buckner, 2010). Young adults making trait judgments for parents engage default network regions of dorsomedial and ventromedial prefrontal cortex, and posterior cingulate cortex (Laurita, Hazan, & Spreng, 2017). Bringing to mind mothers versus close friends recruits medial prefrontal cortex and anterior cingulate cortex, demonstrating that parent-child attachment may modulate engagement of these regions (Wang et al., 2012). Research investigating mentalizing for chronically accessible parents and children could provide crucial support for the cognitive benefits of responsive parenting practices (Feldman, 2012), as responsive, authoritative parenting is linked with strong and secure attachment bonds (Bakermans-Kranenburg, Van Ijzendoorn, & Juffer, 2003). With greater attachment, the decreased cognitive resources needed for attachment figure representation can be diverted to social cognition for less-close or less-predictable others. This may be especially relevant for clinical populations challenged by social attunement, such as children with autism (Baker et al., 2015). To our knowledge, no functional neuroimaging study, to date, has investigated the ways in which chronic accessibility may be borne out in patterns of brain activity when thinking of a parent or child.

Here we use fMRI to examine the neural representation of young adults' parents and older adults' children. We sought to determine how mental representations of parents and children are associated with differential patterns of brain activity, modulated by attachment. We predicted that bringing to mind parents or children would recruit consistent neural systems across individuals in the sample, including regions of the default network. Additionally, based on the chronic accessibility of attachment figure mental representations, we predicted that activation both within these regions and within other areas of the brain would vary as a function of attachment.

Materials and methods

Participants

Participants were 29 healthy, right-handed young adults (16 females, 13 males; M age = 24 years, SD = 3.5 years) and 27 healthy older adults (12 females, 15 males; M age = 67 years, SD = 6 years), with normal or corrected-to-normal visual acuity. Participants had no history of psychiatric, neurological, or other medical

illness that could compromise cognitive functions. Although data were collected from 59 subjects, 3 subjects were excluded from subsequent analyses: 2 young adults for noncompliance and 1 older adult due to brain abnormalities. In accordance with the Institutional Review Board of Cornell University, participants gave written informed consent prior to scanning.

Assessment of attachment to parent/child

We recruited from a pool of eligible individuals, asking that young adult participants have a living parent to whom they felt close and older adult participants have an adult child to whom they felt close. Participants completed a pre-scan survey about their various personal relationships, including their relationships with their specific parent or child. Participants first provided one name per relationship condition in response to prompts (see Laurita et al., 2017 for information regarding pre-scan survey). This survey included a self-report measure of attachment (WHOTO; Fraley & Davis, 1997; Hazan et al., 1991) and relationship length. The WHOTO is an attachment functions measure that determines the people with whom subjects display attachment relationships. Items are based on four attachment features: proximity seeking, separation distress, safe haven, and secure base. Subjects list up to four most important figures in their lives for each of the ten items. The WHOTO can be used in various ways to measure individuals' attachment to others. In the present study, we utilized it as a continuous measure of attachment with parent or child (in contrast to attachment with romantic partner and close friend) by scoring each item based on the individual's ranking (highest scores = listed first) and totaling these scores; therefore higher WHOTO total scores were indicative of greater levels of attachment.

Task and fMRI design

During fMRI scanning, we used a trait-judgment task in which participants were asked to think about several people in their lives mentioned by name in the pre-scan survey. Each trial contained a trait adjective and a person's name; participants rated the person on each trait adjective, on a scale of 1 (unlike this person) to 3 (very much like this person). Blocks were composed of 5 trials in which participants were instructed to hold the person in mind continuously while making each trait judgment about that person. Trait judgments were also made for a romantic partner, friend, acquaintance, famous person, and the self, but are not considered in the current report. See Figure S1 in the Supplemental Material for behavioral

paradigm. Additional details regarding the task and fMRI design can be found in the Supplemental Material.

Magnetic resonance image acquisition

Brain imaging data were acquired using a 3T GE Discovery MR750 MRI scanner with a 32-channel head coil. This MRI scanner was located within the Cornell Magnetic Resonance Imaging Facility in Ithaca, New York. Anatomical scans were acquired using a T1-weighted volumetric MRI magnetization prepared rapid gradient echo (TR = 7.7 ms; TE = 3.4 ms; 7° flip angle; 1.0 mm voxels with no gap, 176 slices). Five 7 m 40 s experimental runs of blood-oxygen level dependent (BOLD) functional scans were acquired with a T2*-weighted multi-echo imaging pulse sequence (TR = 2000 ms; TEs = 12.7, 27.5, and 43 ms; 77° flip angle; 33 axial slices; matrix size = 64 x 64; field of view (FOV) = 240 mm; 33 axial slices; 3.8 mm thick slices).

Preprocessing of magnetic resonance imaging data

BOLD fMRI data were preprocessed to correct for motion, physiological noise and scanner artifacts using Multi-Echo Independent Components Analysis (ME-ICA) with *meica.py* (Kundu, Inati, Evans, Luh, & Bandettini, 2012). ME-ICA is a method for de-noising fMRI data based on information about the T2* decay of the BOLD signal, acquired through multi-echo fMRI. Using ME-ICA, multi-echo fMRI datasets can be decomposed into independent components before these components are categorized as BOLD or noise/non-BOLD. ME-ICA robustly de-noises fMRI data by removing all non-BOLD components (Kundu et al., 2012; Lombardo et al., 2016). The BOLD fMRI images were normalized to a custom young-old population template derived from 50 young (25 female; $M = 22.02y$, $SD = 3.13y$) and 50 older (25 female; $M = 67.14y$, $SD = 6.7y$) adults. Included template subjects were selected from an in-house brain bank for low trait motion, as recent work has indicated that trait motion can bias structural scans (mean FD = 0.09; Savalia et al., 2017). Anatomical images for included subjects were affine registered to MNI space using *@toMNI_Awarp* before being non-linearly, iteratively aligned using *@toMNI_Qwarp* in AFNI. Data were resampled to 2x2x2-voxel volumetric time-series and smoothed with an 8-mm full width half maximum (FWHM) Gaussian kernel.

fMRI analysis

Partial least squares

Analyses were performed using partial least squares (PLS; Krishnan, Williams, McIntosh, & Abdi, 2011;

McIntosh, Chau, & Protzner, 2004), a multivariate functional neuroimaging analysis technique used to identify whole-brain patterns of activity that are correlated with task. PLS identifies a set of orthogonal latent variables that optimally relate BOLD signal and the experimental design or a measure of behavior. PLS results can be interpreted as identifying covarying sets of brain regions in which activity is reliably associated with a specific condition, or where brain activity during a condition of interest covaries with offline behavior, such as WHOTO scores. The behavioral PLS procedure constitutes a between-subjects analysis to assess individual differences in the relationship between attachment and brain activity during mentalizing.

For each analysis, the significance of each latent variable was determined by permutation testing, using 500 permutations with random reordering of the task conditions for each participant. PLS is recalculated for each permutation sample, and the frequency in which the permuted singular value exceeds the observed singular values is determined and expressed as a probability. The reliability of the saliences for the brain voxels across participants, characterizing each pattern identified by a latent variable, was determined by bootstrap resampling with replacement, using 100 iterations, to estimate the standard errors for each voxel. We set a minimum bootstrap ratio (conceptually similar to a Z-score) at 2.58 equivalent to $p < 0.01$. In the current sample, fifty-six total subjects gives us 80% power to detect effect small effect sizes, $r > 0.25$. Because analysis is performed across voxels in a single analytic step, no correction for multiple comparisons is required. Additional details regarding PLS can be found in the Supplemental Material available online.

Results

Behavioral results; assessment of attachment to parent/child

First, we confirmed that parents and children are significant attachment figures. To this end, we conducted repeated measures ANOVA tests across WHOTO total scores for a variety of social others: parent/child, romantic partner, and close friend. Neuroimaging results pertaining to these social others are reported elsewhere (Laurita et al., 2017). In the young adults, there was a significant difference between means of parent, romantic partner, and close friend WHOTO scores ($F(2, 56) = 68.00$, $p < 0.001$). Results of non-parametric analyses mirrored these ANOVA results, as a Friedman test yielded significant differences among repeated measures $\chi^2(2, N = 29) = 40.55$, $p < 0.001$. In the older adults, results also showed a significant

difference between means of child, romantic partner, and close friend WHOTO scores ($F(2, 52) = 127.96, p < 0.001$). Results of non-parametric analyses mirrored these ANOVA results, as a Friedman test yielded significant differences among repeated measures $\chi^2(2, N = 27) = 44.24, p < 0.001$. We conducted both non-parametric tests to account for alternative perspectives that consider WHOTO scores as ordinal data. We ran several post-hoc t-tests to clarify the nature of attachment-related differences between parents/children in comparison to participants' other close social relationships. Young adult participants reported significantly greater attachment to parents over friends ($t_{(56)} = 7.28, p < 0.001, d = 1.91$), and older adults also reported significantly greater attachment to children over friends ($t_{(42)} = 5.75, p < 0.001, d = 1.56$). Taken together, these results demonstrate that participants' parents or children served as attachment figures for our participants. Additionally, we note that levels of attachment varied across our sample, permitting an assessment of individual differences.

To compare across parent and child conditions, we also examined length of relationship for young adults with their named parent and older adults with their named child. Although our sample of parents and children were not related, younger participants' ages were not significantly different from that of the older adults' children ($t_{(26)} = -1.91, p = 0.07, d = 0.55$). Although developmentally very different, this suggests that the parent-child relationship was of similar length between our groups. Descriptive statistics for WHOTO and relationship length are in [Table 1](#).

Table 1. Descriptive statistics for self-report measures.

Measure	Parent (Young Adults)	Child (Older Adults)
WHOTO (<i>M, SD</i>) Out of 40	22.31, 8.46	17.04, 9.65
Length of Relationship (<i>M, SD</i>) In years	22.90, 4.81	29.27, 2.44

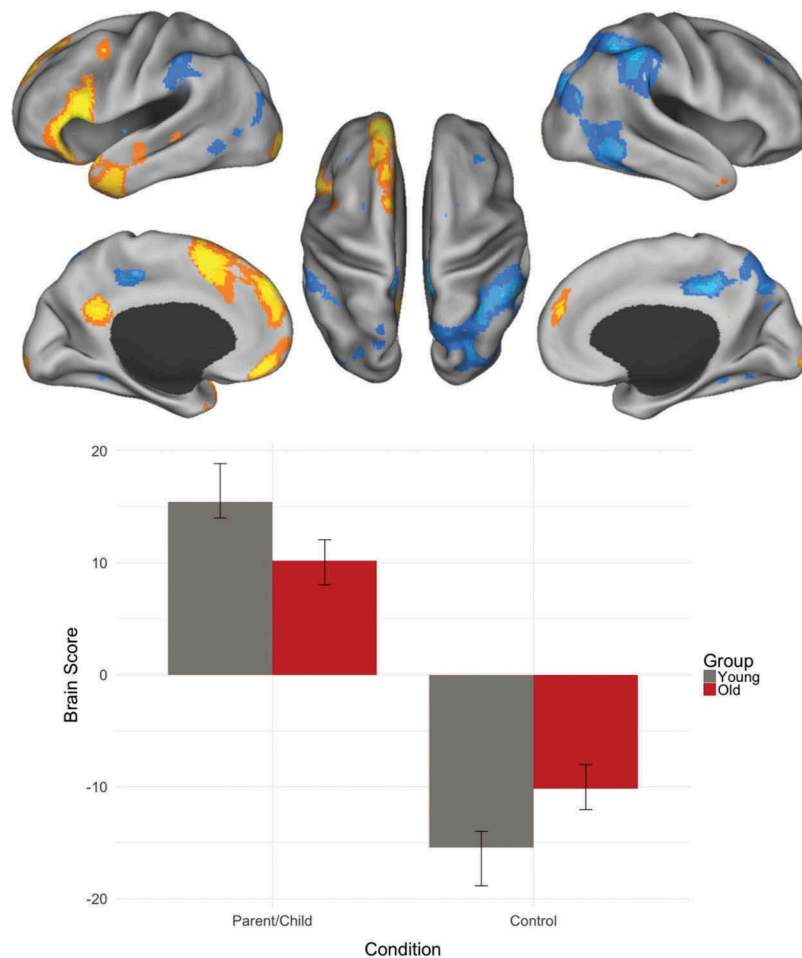


Figure 1. Results of the PLS analysis comparing activity across parent/child and control conditions; LV Activation map (Top) and brain scores with 95% confidence intervals (Bottom). Cool colors on activation maps (shades of blue) correspond to negative brain scores. For activation map: (Left) Lateral and medial views of left hemisphere. (Center) Dorsal view. (Right) Lateral and medial views of right hemisphere.

Neuroimaging results

Brain activation during mentalizing about one's parent or child, relative to the control condition, engaged the default network, consistent with prior reports of mentalizing (e.g., Mar, 2011). This initial task PLS analysis investigated neural activity for parent or child and motor control conditions, revealing one significant pattern of activity, or latent variable. This significant latent variable accounted for 91.53% of the crossblock covariance ($p = .002$). Brain scores for parent and child conditions covaried against the control condition. Significant activations were found within ventromedial and dorsomedial prefrontal cortex, posterior cingulate cortex, superior temporal sulcus, inferior frontal gyrus, occipital pole, cerebellum, caudate, lateral occipital cortex, frontal orbital cortex, brain stem, and temporal occipital fusiform cortex. (Figure 1; see Table 2 for full results).

Central to the aims of the current study, brain activation when mentalizing about one's parent or child significantly varied as a function of attachment ($p = .016$, 78.08% crossblock covariance explained). A significant negative association was observed between WHOTO scores and activity in a number of brain regions. Results showed that the more attached one feels to their parent or child, the lower brain activity was observed in anterior cingulate cortex (ACC), left amygdala hippocampus, anterior and posterior insula, posterior cingulate cortex (PCC), and

Table 2. Peak activation coordinates for trait judgments compared with control condition.

Region	Coordinates			BSR
	x	y	z	
<i>Parent/Child > Control</i>				
Dorsomedial prefrontal cortex	-8	54	32	-14.74
Inferior frontal gyrus	-52	20	2	-13.23
Ventromedial prefrontal cortex	-2	48	-20	-11.57
Occipital pole	-20	-96	0	-10.17
Posterior cingulate cortex	-4	-54	28	-9.47
Cerebellum	20	-84	-38	-8.59
Occipital pole	20	-96	-4	-8.09
Superior temporal sulcus	50	12	-36	-6.14
Cerebellum	6	-60	-42	-5.79
Caudate	-16	10	10	-5.59
Lateral occipital cortex	-46	-62	26	-5.32
Frontal orbital cortex	32	20	-20	-4.77
Brain stem	-2	-26	-8	-4.37
Temporal occipital fusiform cortex	-38	-46	-22	-3.35
<i>Control > Parent/Child</i>				
Superior parietal lobule	32	-50	46	10.79
Inferior temporal gyrus	60	-56	-10	8.99
Cerebellum	-40	-40	-44	7.85
Lateral occipital cortex	-28	-74	28	6.80
Middle frontal gyrus	36	34	38	6.28
Central opercular cortex	50	4	8	6.17
Middle frontal gyrus	-30	30	36	6.04
Cerebellum	18	-58	-50	6.00
Temporal occipital fusiform cortex	-28	-48	-8	5.97
Superior frontal gyrus	-22	4	58	5.66
Frontal orbital cortex	14	26	-26	5.44
Inferior temporal gyrus	-54	-32	-24	5.18
Posterior middle temporal gyrus	12	-28	-24	4.39
Frontal orbital cortex	-12	26	-24	3.98
Anterior cingulate cortex	8	46	0	3.53
Cerebellum	8	-80	-54	3.35
Frontal pole	26	60	-20	3.25

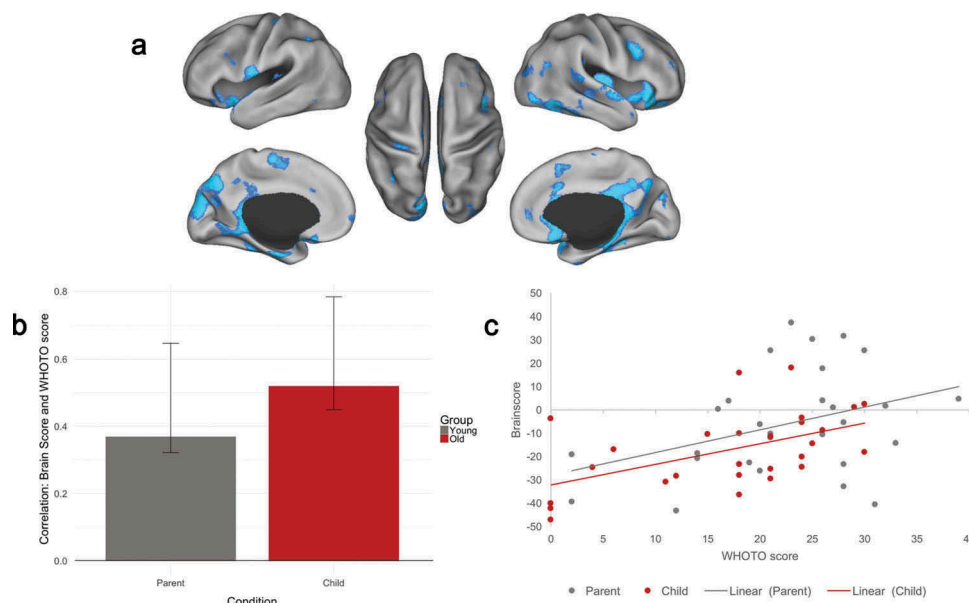


Figure 2. Relationship between parent/child attachment and brain activity while mentalizing. (a) Significant reductions in brain activity as a function of attachment when making trait judgments about parent or child. (b) Bootstrapped correlation values between a composite measure of brain activity and the WHOTO score for each group, revealing similar magnitude of covarying activity in both younger and older adults. (c) Scatterplot of the association between a composite brain activity score (corresponding with decreased BOLD activity in (a)) and attachment (measured by the WHOTO).

Table 3. Peak coordinates that covary as a function of attachment.

Region	Coordinates			
	x	y	z	BSR
<i>Decreased activity as a function of attachment to Parent or Child</i>				
Dorsal anterior cingulate cortex	14	24	26	7.33
Brain stem	6	-34	-12	6.71
Orbitofrontal cortex	2	24	-32	6.44
Amygdala	-22	4	-18	6.20
Supramarginal gyrus	44	-26	32	6.00
Posterior insula	42	-14	10	5.77
Inferior temporal gyrus/Occipital face area	56	-58	-18	5.66
Cuneus	4	-86	34	5.35
Superior parietal lobule	-28	-52	46	5.21
Posterior cingulate cortex	4	-42	40	5.04
Parahippocampus	-18	-12	-30	4.86
Lateral occipital cortex	44	-64	28	4.85
Precentral sulcus	42	-4	38	4.81
Hippocampus	24	-26	-16	4.67
Superior temporal gyrus	64	-2	-10	4.66
Occipital fusiform gyrus	28	-82	-18	4.60
Thalamus	-18	-22	-2	4.49
Fusiform gyrus	-32	-36	-20	4.45
Insula	-36	6	18	4.36
Poster superior temporal sulcus	66	-42	10	4.29
Anterior fusiform gyrus	-30	-2	-48	4.29
Cerebellar vermis	-8	-66	-40	4.22
Anterior insula	26	22	-2	4.19
Occipital face area	-50	-68	-14	4.13
Dorsal anterior cingulate cortex	-14	22	34	4.04
Precentral gyrus	-54	0	2	3.94
Frontal pole	-10	68	-4	3.94
Orbitofrontal cortex	-16	30	-18	3.81
Precentral gyrus	0	-18	66	3.81
Superior frontal gyrus	-18	34	36	3.79
Frontal pole	44	54	16	3.78
Hippocampus	-36	-24	-12	3.75
Lateral occipital cortex	36	-78	4	3.72
Middle frontal gyrus	30	36	50	3.70
Lateral occipital cortex	36	-84	24	3.68
Supplementary motor area	8	10	56	3.67
Anterior insula	-42	26	10	3.41

the putative occipital face area (OFA), as well as other regions (Figure 2; see Table 3 for full results).

Discussion

The present study identified brain regions whose activity varies as a function of attachment. During mentalizing about attachment figures, one's parents or children, brain activity was systematically reduced as a function of perceived closeness. Put another way, when we think about our parents or children, reduced brain activity is observed when we are more bonded to these figures. Importantly, brain regions identified as showing lower activation with higher levels of attachment serve important roles in social navigation (e.g., Tavares et al., 2015). This inverse relationship between brain activity and attachment scores provides the first empirical support for a neural mechanism underlying the chronic accessibility of attachment figure mental representations. It is possible, although certainly an alternate mechanism not

yet identified that facilitates the attachment effect may be involved, that conditioning to the presence of an attachment figure allows us to readily access our representations of that person without taxing cognitive and neural resources.

Mental representations of attached parents and children comprise highly salient experiences and, as such, are differentiable from other social mental representations. Decreased activation was observed in regions implicated in past findings on attachment figure representations. ACC and insula activity is associated with distress and pain alleviation by close others (Coan, Schaefer, & Davidson, 2006). These regions are involved in the salience network (Seeley et al., 2007), a collection of brain regions that coordinates responses to meaningful environmental stimuli (Uddin, 2015). PCC is a known default network hub, recruited in social cognitive processes, such as mentalizing, for close others (e.g., Krienen et al., 2010; Laurita et al., 2017). Results of the present study add nuance to the association between default network activity and social closeness; one interpretation of the convergence of these findings would be that PCC remains online while individuals cognitively represent non-attached social others. Decreased activation of left amygdala with greater attachment is likely related to the region's processing of fear versus safety signals (Phelps et al., 2001). The hippocampal memory system plays a role in social cognition, specifically in integrating information on relative social affiliation and power (Tavares et al., 2015; for review, see Laurita & Spreng, 2017). Our results provide evidence that hippocampus-supported social memory is necessitated only by less chronically accessible close others. OFA is putatively implicated in face perception and, particularly, in recognition of unfamiliar faces and objects (Gauthier, Skudlarski, Gore, & Anderson, 2000); less recruitment of OFA for attached parents and children supports chronic accessibility, as these figures are easily recognizable and highly familiar.

These findings enhance our understanding of the neural representation of some of the most important people in our lives – parents and children – and illuminate how attachment modulates these representations. The profound impact of attachment figure representations on individuals' affective and physiological regulation (Pietromonaco et al., 2006) and expectations for social-other responsiveness in future interactions (Andersen & Cole, 1990) is already well-documented. The present results provide novel evidence that one critical evolutionary advantage of attachment bonds is the conservation of valuable neural and cognitive resources in conferral of regulatory benefits. Attachment figures need not be physically present to promote our well-being and, by merely

bringing them to mind we can alleviate the cognitive load of social processing.

Future work should explore this neural mechanism for chronic accessibility as it relates to our ability to navigate the complex social world around us.

Author Contributions

All authors, A. C. Laurita, C. Hazan, and R. N. Spreng, developed the study concept and contributed to the study design. A. C. Laurita performed data collection and analysis under the supervision of R. N. Spreng. A. C. Laurita and R. N. Spreng contributed to interpretation of the data. A. C. Laurita and R. N. Spreng wrote the paper. All authors approved the final version of the manuscript for submission.

Disclosure statement

No potential conflict of interest was reported by the authors.

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