Brain Mechanisms for Processing Affective Touch

Ilanit Gordon, Avery C. Voos, Randi H. Bennett, Danielle Z. Bolling, Kevin A. Pelphrey, and Martha D. Kaiser*

Yale Child Study Center, Yale University School of Medicine

Abstract: Despite the crucial role of touch in social development, there is very little functional magnetic resonance imaging (fMRI) research on brain mechanisms underlying social touch processing. The "skin as a social organ" hypothesis is supported by the discovery of C-tactile (CT) nerves that are present in hairy skin and project to the insular cortex. CT-fibers respond specifically well to slow, gentle touch such as that which occurs during close social interactions. Given the social significance of such touch researchers have proposed that the CT-system represents an evolutionarily conserved mechanism important for normative social development. However, it is currently unknown whether brain regions other than the insula are involved in processing CT-targeted touch. In the current fMRI study, we sought to characterize the brain regions involved in the perception of CT-supported affective touch. Twenty-two healthy adults received manual brush strokes to either the arm or palm. A direct contrast of the blood-oxygenation-level-dependent (BOLD) response to gentle brushing of the arm and palm revealed the involvement of a network of brain regions, in addition to the posterior insula, during CT-targeted affective touch to the arm. This network included areas known to be involved in social perception and social cognition, including the right posterior superior temporal sulcus and the medial prefrontal cortex (mPFC)/dorso anterior cingulate cortex (dACC). Connectivity analyses with an mPFC/dACC seed revealed coactivation with the left insula and amygdala during arm touch. These findings characterize a network of brain regions beyond the insula involved in coding CT-targeted affective touch. *Hum Brain Mapp 00:000–000, 2011.* © 2011 Wiley Periodicals, Inc.

Key words: C-tactile; fMRI; neuroimaging; touch; social brain

INTRODUCTION

Great strides have been made in identifying a specialized neural network involved in social visual perception (e.g., Adolphs, 2003; Allison et al., 2000; Insel and Fernald, 2004; Frith and Frith, 2010), yet the neural mechanisms underlying social touch perception have received much less attention. An expanding literature on touch perception implicates the posterior insula as a key structure for processing caressing, light touch to hairy skin (Olausson et al., 2010), unique in the fact that it contains C-tactile (CT) nerves. The "skin-as-a-social-organ" hypothesis (Morrison et al., 2010) builds on evidence from the role of these CT-fibers in processing gentle touch, the kind which is common in social interactions (Björnsdotter et al., 2010). The existence of CT-fibers in mammals (Kumazawa and Perl, 1977), including humans (Vallbo et al., 1993), suggests a conserved evolutionary mechanism for affective touch perception. If the CT system supports social processing of touch, key nodes of the "social brain" (Brothers, 1990), a complex neural network specialized to support social function beyond the insula, such as the medial prefrontal cortex (mPFC), anterior cingulate cortex (ACC), superior temporal sulcus (STS), and amygdala, may be involved in the perception of CT-targeted affective touch.

Olausson et al. (2010) have conducted a series of elegant studies with healthy and patient populations establishing the existence of slow-conducting, unmyelinated CT-fibers

*Correspondence to: Martha D. Kaiser, Yale Child Study Center, Yale University School of Medicine, 230 South Frontage Road, New Haven, CT 06520. E-mail: martha.kaiser@yale.edu

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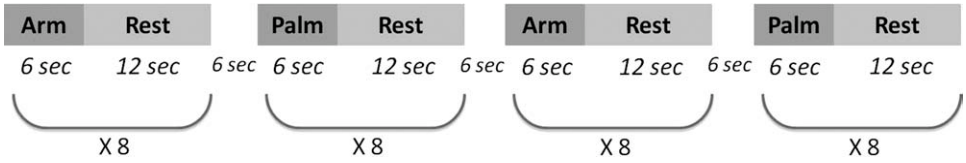

Figure 1.
fMRI pleasant touch procedure.

present in hairy skin that are thought to support the perception of dynamic social touch such as light stroking to the forearm. Although CT-afferents function poorly in localizing or discriminating touch, they are especially sensitive to gentle touch (McGlone et al., 2007). Two patients with a rare neuronopathy syndrome causing specific losses of A-B fibers but spared CT fibers exhibit deficits in touch discrimination. However, these patients can detect gentle strokes to hairy skin (either arm or thigh; Olausson et al., 2002; Olausson et al., 2008; Cole et al., 2008). Functional magnetic resonance imaging (fMRI) studies indicated that in these patients and in healthy adults, targeting CT-afferents with gentle touch resulted in activation of posterior insular cortex contralateral to the stroked region (Björnsdotter et al., 2009; Olausson et al., 2002), suggesting that CT-afferents support socioemotional processing and interocpetion of pleasant touch (Löken et al., 2009). Considering the fundamental role of touch in development and social processes, it is essential to explore whether additional components of the social brain beyond the insula are involved in processing CT-targeted touch.

We sought to identify brain mechanisms that support the perception of CT-targeted pleasant touch in healthy adults. We predicted that "social brain" regions beyond the insula would be involved in processing such affective touch. We tested this hypothesis by contrasting the neural response to CT-optimal gentle touch administered to the hairy skin of the arm versus the glabrous skin of the palm. This is the first fMRI study to directly contrast the brain response to gentle touch processed by CT and non-CT areas of the skin (see also McCabe et al., 2008) enabling a thorough (i.e., whole brain) characterization of neural mechanisms supporting affective touch processed by CT-afferents.

MATERIALS AND METHODS

Participants

We studied a group of 22 right-handed adults (nine females) ranging in age from 19 to 35 years (Mean = 24.52, SD = 3.56). Written consent was obtained for each participant according to a protocol approved by the Yale School of Medicine Human Investigations Committee. Participants received $50 for their participation in the study.

Prescan Behavioral Ratings

Before the scan, participants were brushed on the right arm and palm by the experimenter in the same manner that they would be brushed during the fMRI scan. For the arm and palm separately, we asked participants to indicate if they had felt the touch (all participants indicated that they had). Then, participants were asked to indicate how pleasant they would rate the touch to the arm and palm separately on a 1–5 Likertscale (1 = "Not at all," 2 = "Slightly," 3 = "Moderately," 4 = "Very," 5 = "Extremely"). Finally, participants were asked to write in their own words what the touch felt like separately for the palm and arm. Nineteen of 22 participants completed the prescan ratings.

Experimental Design

Participants received continuous brushing (back and forth) to the right palm or forearm in a block design procedure. There were two blocks of each condition (arm, palm), each of which included eight repetitions of 6-s periods of touch followed by 12 s of rest (no touch). Between each block, there were six additional seconds of rest to allow the experimenter to prepare for the next block of touch in an alternate position (See Fig. 1). Before the beginning of the scan, we measured and marked 8 cm on the arm and 4 cm on the palm to control for the length of area brushed. Tactile stimuli were slow strokes (8 cm/s) with a 7-cm wide watercolor brush administered by two trained experimenters. The velocity of the brush strokes was chosen as it was previously found to be optimal for targeting CT afferents (Löken et al., 2009; Morrison et al., 2010). Before data acquisition, participants were instructed by the experimenter to close their eyes during the procedure, to remain very still, and to focus on the touch they experienced (an fMRI-compatible camera mounted on the head coil was utilized by experimenters to confirm that participants kept their eyes closed for the duration of the experiment). Overall, the procedure lasted for 10.03 min (602 s) with an initial 10-s fixation, which was later discarded from analysis.

Imaging Protocol

Images were collected on a Siemens 3T Tim Trio scanner located in the Yale University Magnetic Resonance

Research Center. High-resolution T1-weighted anatomical images were acquired using an MPRAGE sequence (TR = 1,230 ms; TE = 1.73 ms; FOV = 256 mm; image matrix 256^2; 1 × 1 × 1 mm). Whole-brain functional images were acquired using a single-shot, gradient-recalled echo planar pulse sequence (TR = 2,000 ms; TE = 25 ms; flip angle = 60°; FOV = 220 mm; image matrix = 64^2; voxel size = 3.4 × 3.4 × 4.0 mm; 34 slices) sensitive to blood-oxygenation-level-dependent (BOLD) contrast. Runs consisted of the acquisition of 306 successive brain volumes.

fMRI Analysis

Data were processed and analyzed using the BrainVoyager QX 2.0.08 software package (Brain Innovation, Maastricht, The Netherlands). Preprocessing of the functional data included slice time correction (using sinc interpolation), three-dimensional rigid-body motion correction (using trilinear-sinc interpolation), spatial smoothing with a FWHM 4-mm Gaussian kernel, linear trend removal, and temporal high-pass filtering (GLM with Fourier basis set, using two cycles per time course). Functional datasets were coregistered to within-session anatomical images, which were in turn normalized to Talairach space. fMRI slices were oriented anterior–posterior comissure. Estimated motion plots and cine loops were examined for each participant. Over the entire scan session, no participant's head position deviated from the position at first volume acquisition by greater than 2 mm of translation in any direction or two degrees of rotation about any axis. Additionally, no participant had greater than 1 mm degree of translation or rotation between two consecutive volumes or greater than 2 mm degrees of translation or rotation integrated over four consecutive volumes.

General linear model (GLM)-based analyses were conducted for each participant to assess task-related BOLD responses. Regressors were defined as boxcar functions with values of 1 during each condition and 0 otherwise, convolved with a double-gamma hemodynamic response function (HRF). Predictors depicting motion in all six parameters were included as predictors of no-interest.

Whole Brain Analyses

All group-level analyses were limited to only voxels within the extent of the MNI brain normalized to Talairach space. This whole brain mask consisted of 1,449,746 (1 × 1 × 1 mm) voxels. Whole brain investigations were conducted using random-effects (RFX) GLM-based analyses. Analyses of each touch condition separately were assessed at a threshold of $q < 0.05$, and were corrected for multiple comparisons using cluster thresholds determined by the Brain Voyager QX cluster-level statistical threshold estimator plug-in (Forman et al., 1995; Goebel et al., 2006). After 1,000 iterations of a Monte Carlo simulation, the relative frequency of each cluster size was evaluated, and the cluster size corresponding to a corrected threshold of $\alpha < 0.05$ was determined. For the individual contrasts (arm > baseline and palm > baseline), a cluster threshold of 12 voxels was calculated. For the direct contrast of touch conditions (arm > palm), results were assessed at a false discovery rate (FDR) threshold of $P < 0.05$ (Genovese et al., 2002). These results were further corrected with a cluster threshold of 34 voxels (918 cubic mm) calculated to correspond to $\alpha < 0.05$. The results of the individual contrasts (arm > baseline and palm > baseline) were more robust than the direct contrast of the arm and palm. Thus, a more stringent threshold (q and not P) was implemented to discern distinct regions of activation. Although, cluster thresholding is not a necessary step when correcting with a false discovery rate (FDR) method, we did so for the arm > palm for two reasons: (1) We aimed to be consistent with the method of correction applied in the individual contrasts when approaching the arm > palm contrast. (2) Using the same corrections for the arm > palm, as we did in the individual contrasts allows us to focus and report on regions that have more prominent activations and are statistically less "prone" to represent false discoveries.

Functional Connectivity Analysis

A psychophysiological interaction (PPI) analysis (Friston et al., 1997) was used to investigate differences in functional connectivity during arm touch compared to palm touch. Before connectivity analyses, the global mean (averaged signal across voxels) was removed from each volume, as a substitute method for removing physiological artifacts (Fox et al., 2005). A region of the medial prefrontal cortex that extends to the dorsal anterior cingulate cortex (ACC) functionally defined by having greater activation during arm versus palm was used as a seed for the connectivity analysis. The mPFC/dACC was chosen as a seed due to its known role in a range of social perception and cognition tasks (Amodio and Frith, 2006; Mar, 2011; Sperduti et al., 2011). This ROI extends into the dorsal ACC which is also of interest as it has been shown to relate to affective processing, social valuation and affect regulation (for reviews, see Bush et al., 2000; Devinsky et al., 1995) PPI analyses were restricted to two other regions of the social brain, bilateral insula and amygdala. Thus, we aimed to test our hypothesis that during arm touch, a network of key structures of the social brain coactivate, functioning together to process CT targeted touch. PPI regressors for each participant were created by multiplying the preprocessed, normalized time course from the seed region with the difference of the two task regressors convolved with the HRF. This PPI regressor, along with the two task regressors and the region time course were modeled as predictors for each participant, which were in turn combined in a multiparticipant random-effects GLM analysis. Using a mask defined structurally with the Talairach database (Lancaster et al., 1997, 2000), the

TABLE I. Results of the arm versus baseline analysis

	Peak *X*	Peak *Y*	Peak *Z*	*T*(21)	*P*	Number of voxels
R supramarginal gyrus	42	–28	22	6.436358	0.000002	3,535
R pSTS	51	–46	4	6.867306	0.000002	2,104
R ventrolateral PFC	30	32	10	6.472061	0.000001	1,422
R temporal pole	45	–7	–26	6.086636	0.000002	502
R cerebellum	18	–61	–20	5.832438	0.000005	1,107
R dorsomedial PFC	12	32	40	5.949948	0.000009	1,026
L mPFC/dACC	–3	29	34	5.436646	0.000007	507
L dorsomedial PFC	–9	23	52	5.754639	0.000022	492
L cerebellum	–36	–61	–29	5.423954	0.00001	1,054
L somatosensory cortex	–48	–46	43	5.701232	0.000022	1,789
L insula and supramagrinal gyrus	–54	–22	19	7.700993	0	7,369

Results from contrasting of arm > baseline at $q < 0.05$, $k > 12$.

multiparticipant GLM analysis was limited to voxels within bilateral insula and amygdala. The PPI function was used as the only predictor of interest and was assessed at a threshold of $P < 0.05$.

RESULTS

Prescan Behavioral Results

The means (*M*) and standard errors (SE) for rating pleasantness of touch to the arm and to the palm were $M = 3.272$, $SE = 0.163$; $M = 2.842$, $SE = 0.206$ (for arm and palm, respectively). A paired samples *t*-test revealed that arm touch was rated as significantly more pleasant than palm touch: $t(18) = 2.388$, $P < 0.05$. However, overall participants rated the brush strokes to both arm and palm as pleasant. Similar types of comments were given for arm and palm touch. For example, participants described arm touch as pleasant, soft and cozy on my skin, and furry. Palm touch was described as nice, like soft fur, and a feather light caress.

Whole Brain Results

To determine whether we replicated previous findings of gentle touch to the arm and palm relative to baseline (Olausson et al., 2002), we conducted multiparticipant RFX GLM-based analyses for the contrasts of arm > baseline and palm > baseline, respectively. These contrasts were both assessed at a false discovery rate (FDR) threshold of $q <$ 0.05corrected for multiple comparisons with a minimum cluster size of 12 contiguous voxels (324 cubic mm) corresponding to $\alpha < 0.05$. The results of these analyses are shown in Tables I and II and Figure 2. As illustrated in Figure 2, both of these contrasts revealed robust activations in the left, mid, and posterior insula, right temporoparietal junction, and somatosensory cortex. It seems that activations in pSTS and mPFC/dACC were unique in the arm condition.

To assess differences between the two brushing conditions, we directly compared the BOLD response to arm and palm touch, at a threshold of $P < 0.05$ with a cluster threshold of 34 contiguous voxels (918 cubic mm). The results of this contrast were less robust compared to the individual contrasts; hence, a less stringent threshold was

TABLE II. Results of the palm versus baseline analysis

	Peak *X*	Peak *Y*	Peak *Z*	*T*(21)	*P*	Number of voxels
R inferior parietal lobe	51	−40	28	6.849833	0.000001	841
R supramarginal gyrus	42	−28	22	7.516451	0	1,482
R inferior frontal gyrus	36	29	31	4.97086	0.000064	350
R ventrolateral PFC	42	41	4	5.382156	0.000024	846
R cerebellum	27	−40	−23	6.099323	0.000005	4,218
	18	−49	−41	4.597342	0.000156	375
L striatum	−18	−10	16	5.659114	0.000013	686
L cerebellum	−21	−52	−32	7.021409	0.000001	3,393
L insula and supramarginal gyrus and somatosensory cortex	−48	−22	25	7.532726	0	12,990

Results from contrasting of palm > baseline at $q < 0.05$, $k > 12$.

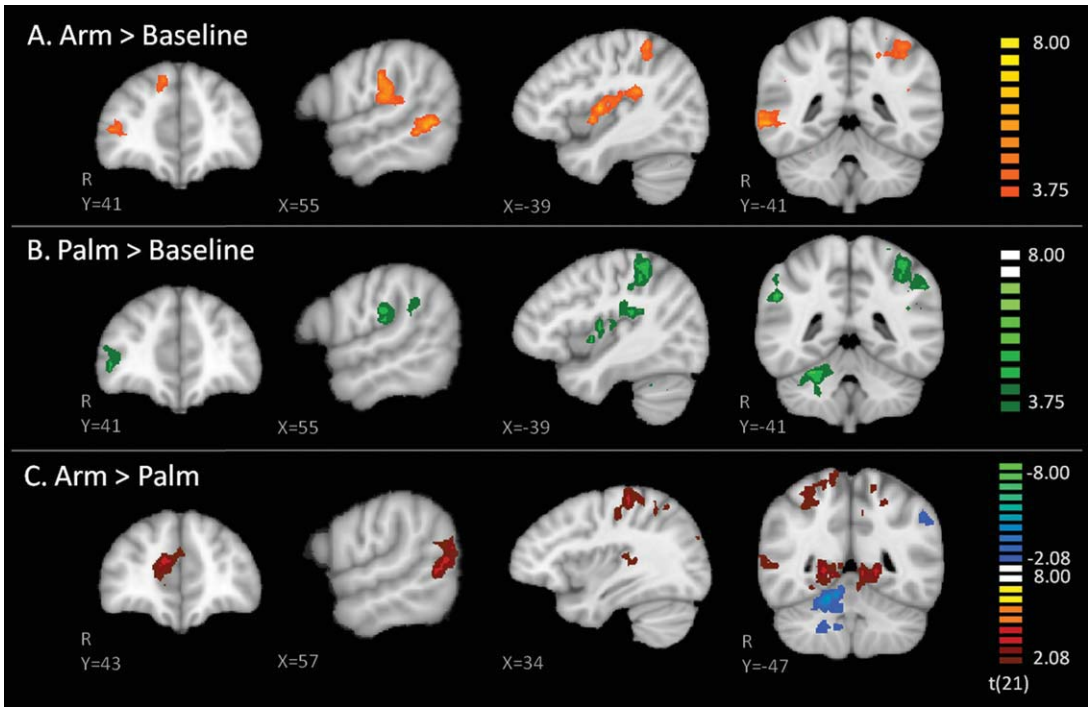

Figure 2.

Individual conditions, (**A**) arm and (**B**) palm versus baseline, at $q < 0.05$, $k > 12$. Similar activations can be seen in the left mid and posterior insula, temporoparietal junction, and somatosensory cortex. Arm touch uniquely activates the right posterior superior temporal sulcus and the medial prefrontal cortex. Palm touch uniquely activates the right cerebellum. (**C**) Results from a direct contrast of arm > palm at $P < 0.05$, $k > 34$.

used here to discern regions of activation. The direct arm > palm contrast revealed greater activation to arm touch in the right posterior insula, right posterior superior temporal sulcus (pSTS), and right mPFC/dACC—See Figure 2C and Table III. Deactivations in this contrast represent regions that displayed greater activation to palm relative to arm. Deactivations were found in the right cerebellum and left parietal cortex (see negative activations in Fig. 2C and negative *t* values in Table III). Waveforms for arm and palm are presented in Figures 3 and 4 depicting the hemodynamic response time courses for the two types of touch in the right mPFC/dACC and right pSTS, respectively. Relative to arm, palm elicited a similar, yet, diminished response in the right pSTS. The hemodynamic response time course within the right mPFC/dACC is markedly different across the two touch conditions.

Connectivity Analysis

The PPI analysis assessing task-modulated functional connectivity between a mPFC/dACC seed region and structurally defined areas of bilateral insula and amygdale, identified regions within left insula and left amygdala exhibiting greater functional connectivity to right mPFC/dACC during arm touch relative to palm touch (see Fig. 5). Peak coordinates, statistical values, size, and anatomical labels for the regions of differential functional connectivity are provided in Table IV.

DISCUSSION

The current study examines social brain function during the experience of CT-targeted affective touch. Independent contrasts of gentle touch to the arm and palm, each relative to baseline, elicited similar activations in the left mid and posterior insula, temporoparietal junction, and somatosensory cortex. Arm touch uniquely activated the right pSTS and the mPFC/dACC. A direct contrast of touch to the arm and palm singled out brain mechanisms that specifically support the perception of CT-targeted gentle touch including the right pSTS, right posterior insula and right mPFC/dACC. Touch to the palm compared to arm resulted in increased activations in the right cerebellum and left parietal cortex. Finally, a task-related functional connectivity analysis revealed that during gentle touch to the arm compared to palm activation in right mPFC/dACC showed greater connectivity with left insula and amygdala.

TABLE III. Results of the arm versus palm analysis

	Peak *X*	Peak *Y*	Peak *Z*	*T*(21)	*P*	Number of voxels
R pSTS	57	−55	13	3.90213	0.000821	1,981
R posterior insular cortex	36	−28	7	4.592751	0.000158	1,091
R intraparietal sulcs and somatosensory cortex	27	−25	61	4.847011	0.000086	9,381
R visual cortex	6	−91	16	5.302511	0.000029	29,481
L somatosensory cortex	−24	−31	55	3.257685	0.003763	1,380
R mPFC/dACC	9	41	22	4.59207	0.000158	1,752
R cerebellum	15	−43	−20	−7.545203	0	4,619
L parietal cortex	−45	−52	46	−6.354175	0.001533	17,086

Results from a direct contrast of arm > palm at $P < 0.05$, $k > 34$. Note that negative *T* values indicate regions that were more active to palm relative to arm.

Although discriminatory aspects of touch have been extensively examined in neuroscientific research, socioemotional aspects of touch processing have only recently been studied with neuroimaging methods (for review, see Morrison et al., 2010). Building on recent discoveries regarding the role of the CT system in mediating affective processing of touch (Björnsdotter et al., 2010) and the "skin as a social organ hypothesis," we examined the brain response to CT-optimal touch on the arm relative to the palm. Our prescan behavioral analysis revealed that participants rated both arm and palm touch as pleasant. We utilized a whole brain analysis approach and thus were able to identify a network of regions, beyond the insula, which support the perception of CT-targeted touch. Secondary connectivity analyses focused on key nodes of the social brain (mPFC/dACC, insula, and amygdala), enabling a more thorough characterization of the brain mechanisms involved in processing CT-supported affective touch.

Our study replicates and extends previous studies on the brain mechanisms underlying the perception of touch processed by the CT system (e.g., Olausson et al., 2002). As in past studies, we find posterior insula activation specifically in response to CT-targeted touch, which compliments data from studies of patients lacking A-B fibers (Olausson et al., 2002) and may reflect this region's role in tactile recognition and interoception (Augustine, 1996; Björnsdotter et al., 2010). Although past studies implicate insula activation contralateral to the brushed arm, our results implicate ipsilateral insular activations. This raises an issue of laterality that demands further exploration in

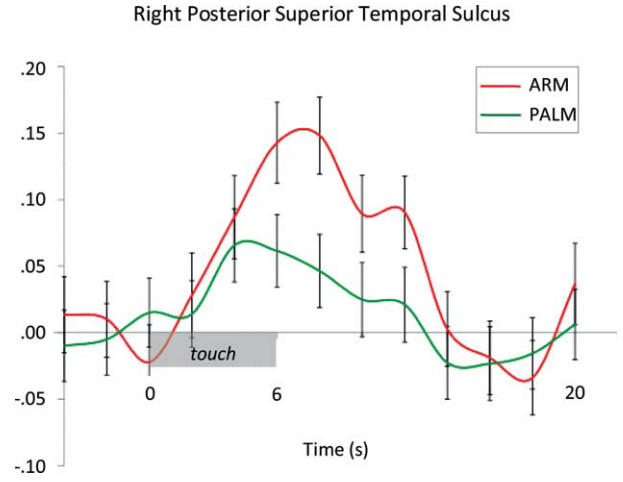

Figure 3.
The graph shows the time course of the percentage change in the BOLD response from the voxels in the right posterior superior temporal sulcus for the arm and palm conditions. The graph shows grand averages obtained by averaging the percentage signal change of individual voxels across all participants. Error bars indicate standard errors of the means. The 0-s time point represents the onset of the touch.

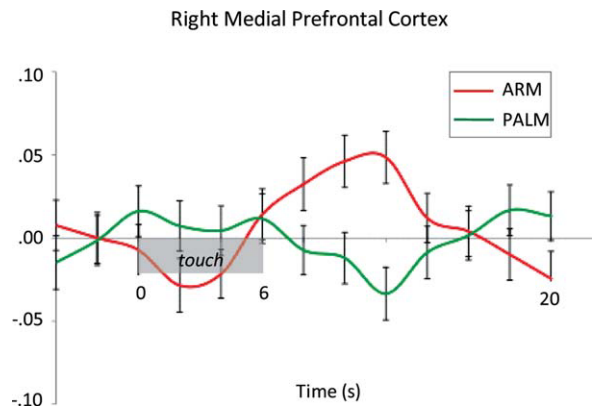

Figure 4.
The graph shows the time course of the percentage change in the BOLD response from the voxels in the right medial prefrontal cortex for the arm and palm conditions. The graph shows grand averages, obtained by averaging the percentage signal change of individual voxels across all participants. Error bars indicate standard errors of the means. The 0-s time point represents the onset of the touch.

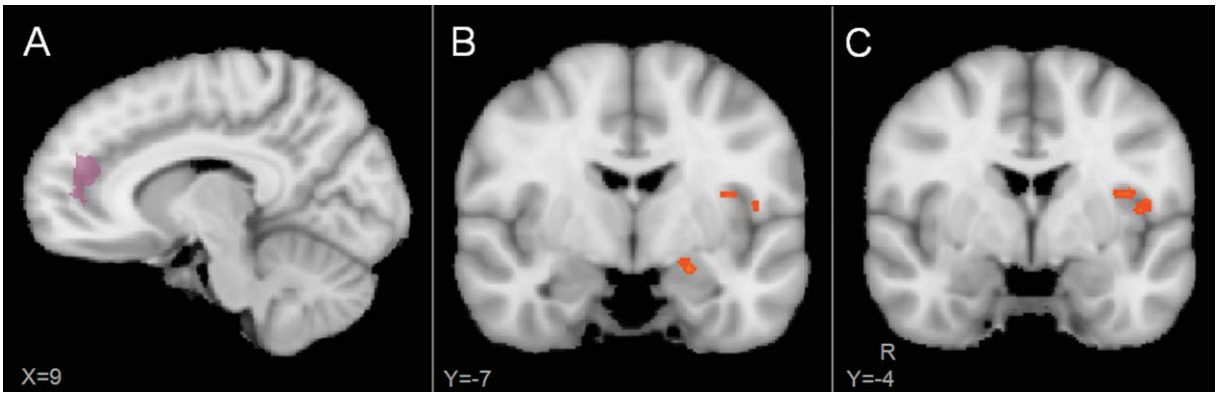

Figure 5.

PPI analysis of arm > palm, $P < 0.05$, $k > 2$, using the right medial prefrontal cortex/dorsal anterior cingulate cortex ROI from the arm > palm contrast as a seed (**A**) and an anatomically defined bilateral amygdala and insula mask. Greater activations to arm relative to palm were found in the left amygdala (**B**) and left insula (B, **C**).

future studies. Moreover, it is important to note that posterior insula activations were found in this study for pleasant touch to the arm and palm relative to baseline (see Fig. 2A,B) whereas in the past posterior insula has been reported to uniquely support CT-optimal touch to non-glabrous skin (Olausson et al., 2002). This difference may be due to the stroking velocity that was chosen for the current study, which may be considered a relatively fast velocity within the CT-optimal range delineated by Löken et al. (2009). A recent report points to the importance of speed to posterior insular activation (Morrison et al., 2011) as brushing velocity of 3 cm/s gave rise to stronger BOLD activations in posterior insula compared to a nonoptimal speed of 30 cm/s. Future studies may incorporate multiple stroking speeds within the optimal range of eliciting CT-fiber activity to examine whether a more distinct differentiation insular activation could be achieved when targeting glabrous versus hairy skin. In addition, differences in our results may be due to the large sample of the current study and methodological differences between our design and earlier designs (i.e., the current study used longer rest periods between brush strokes and continuous brush strokes during touch periods). We chose to extend the rest period between touch intervals from 6 to 12 s as CT afferents have been recently shown to have a relatively slow and delayed conductance (Björnsdotter et al., 2010).

The current fMRI study investigated the neural mechanisms involved in processing effective touch by directly contrasting the brain responses to CT-targeted gentle brushing to the arm and palm. This direct contrast enabled us to isolate a network of regions involved in the perception of touch processed specifically by the CT system. We found several brain regions, beyond the insula, that are involved in the perception of CT-targeted touch (arm relative to palm). These include the right pSTS and right mPFC extending to the dACC. As CT-afferents are present in the hairy skin of the arm and absent in the glabrous skin of the palm, this direct contrast suggests a strong role for this network of regions in the processing of CT-targeted touch. These results highlight the involvement of key nodes of the "social brain" that are implicated in socio-emotional process while sensing pleasant touch that is processed by the CTsystem. The mPFCis well known for its involvement in theory of mind and mentalizing abilities (for reviews see Mar, 2011; Sperduti et al., 2011), and is implicated in inferring other people's intentions and mental states as well as attributing emotional states to others. The ACC's involvement in socioemotional processing (Bush et al., 2000; Devinsky et al., 1995) is also extremely relevant to processing affective aspects of touch. Additionally, the pSTS has been extensively implicated in social perception, mostly focused in the visual and auditory domains (Allison et al., 2000; Hein and Knight, 2008; Kaiser et al., in press; Pelphrey et al., 2011). The involvement of such brain regions in processing CT-targeted touch supports the "skin as a social organ" hypothesis. Although the touch in the current study was that of a soft brush, this gentle touch is consistently rated as pleasant and optimally activates CT nerves. The slow velocity and softness are characteristic of touch that is most likely to be

TABLE IV. Results of the PPI analysis using R mPFC/dACC seed

	Peak X	Peak Y	Peak Z	T(21)	P	Number of voxels
L mid-insula	−21	−7	−11	3.92	0.000783	93
	−36	−4	16	2.98	0.007066	99
L amygdala	−42	−4	10	2.75	0.01208	73

This table shows the results of the PPI analysis using the right medial prefrontal cortex seed (functionally defined in the arm versus palm contrast) and bilateral insula and amygdala masks.

observed in close affiliative bonds (Olausson et al., 2008). Future studies should assess whether the social brain regions implicated in this study activate similarly to human touch as they did to the brush stimulus in our study, perhaps manipulating gentle touch administered by close friends, romantic partners, or caretakers.

A connectivity analysis using the mPFC/dACC as a seed region indicated that the insula and the amygdala were specifically involved in the processing of touch to the arm. The amygdala's function in social processing is vast, dynamic, and complex (for review, see Adolphs, 2010). We speculate that its involvement in processing CT-targeted touch may represent a signaling of biological relevance (Sander et al., 2003) or reward and motivation as this region has been implicated in tracking the identity and the social value of conspecifics (Gothard et al., 2007). The amygdala's connection with the prefrontal cortex has been described as a part of the circuitry that helps determine the current value of stimuli (Hampton et al., 2007). Perhaps the coactivation of the amygdala, mPFC/dACC, and insula during pleasant touch-targeting CT-fibers represents a coding of the social relevance and social reward of the stimuli. The connections between these three structures represent a novel finding of a dedicated circuitry for socio-emotional processing and evaluation of CT-targeted pleasant touch.

Fully characterizing the brain mechanisms involved in processing affective touch is extremely important given the central role of touch hedonics in early development and social function throughout the lifespan (Essick et al. 2010). Typically, warm physical contact and affective touch are integral parts of the earliest interactions between infants and caretakers and close relationships throughout the lifespan (Bowlby, 1969). In autism spectrum disorders (ASD), a disorder in which dysfunction in touch hedonics is often observed, tactile symptoms are considered part of core pervasive deficits in social functioning and communication (Cascio, 2010; Kanner, 1943; Waterhouse et al., 1996). Interestingly, some of the same brain regions found to support typical processing of affective touch in the current study (e.g., amygdala and pSTS) have been reported as hypoactive in children with ASD during visual social perception tasks (e.g., Kaiser et al., 2010). To the extent that disrupted brain mechanisms for social perception extend beyond the visual domain, the brain response to CT-targeted affective touch maybe disrupted in ASD. Current work in our laboratory is addressing this question.

C-tactile fibers react specifically well to gentle, soft touch whereas they are not involved in temporal or spatial discrimination of touch (Essick et al., 2010). However, pleasant touch is not only coded by these afferents. Soft touch administered to glabrous skin (palm) was also considered somewhat pleasant in this study and elsewhere (Krämer et al., 2007). As cognitive processes affect touch hedonics (McCabe et al., 2008), further study is needed to dissect top-down and bottom-up aspects of the neural mechanisms involved in processing affective touch. It is also important to consider that innervation of glabrous and hairy skin is differentiated not only by CT fibers but also by other functions. For instance, myelinated fibers are irregularly distributed with higher densities around the hair follicle in hairy skin compared to their homogenous population of glabrous skin. These nerve fibers' course is sinuous and winding in glabrous skin, but straight and stretched in hairy skin (Provitera et al., 2007). Additionally, Meissner corpuscles exist uniquely in glabrous skin encoding for discriminative aspects of touch, whereas in hairy skin the hair follicle endings are considered to serve thisrole (Ridley, 1970). These differences may contribute to the differential neural response to arm and palm touch. The unique contribution of this study to the touch literature is in identifying a network of "social brain" regions that process CT-targeted touch, supporting our hypothesis that CT fibers serve a specific function in social processing of touch and extending our understanding of "social brain" function from the visual to the tactile domain.

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