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Cognitive influences on the affective representation of touch and the sight of touch in the human brain

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We show that the affective experience of touch and the sight of touch can be modulated by cognition, and investigate in an fMRI study where top-down cognitive modulations of bottom-up somatosensory and visual processing of touch and its affective value occur in the human brain. The cognitive modulation was produced by word labels, `Rich moisturizing cream' or `Basic cream', while cream was being applied to the forearm, or was seen being applied to a forearm. The subjective pleasantness and richness were modulated by the word labels, as were the fMRI activations to touch in parietal cortex area 7, the insula and ventral striatum. The cognitive labels influenced the activations to the sight of touch and also the correlations with pleasantness in the pregenual cingulate/orbitofrontal cortex and ventral striatum. Further evidence of how the orbitofrontal cortex is involved in affective aspects of touch was that touch to the forearm [which has C fiber Touch (CT) afferents sensitive to light touch] compared with touch to the glabrous skin of the hand (which does not) revealed activation in the mid-orbitofrontal cortex. This is of interest as previous studies have suggested that the CT system is important in affiliative caress-like touch between individuals.

Keywords: cognition and emotion; cognition and touch; orbitofrontal cortex; anterior cingulate cortex; insular cortex

INTRODUCTION

Understanding how cognition interacts with reinforcers such as touch is important in the wider context of understanding affect, emotion, affiliative behavior and their brain mechanisms and disorders. The principal aim of this study is to investigate where cognition influences the representation of touch and of the sight of touch in the human brain. Where do top-down cognitive influences from the high level of language influence the affective representation of bottom-up inputs produced by touch and the sight of touch? We performed a study in which the forearm was rubbed with a cream, but this could be accompanied by a word label that indicated that it was a rich moisturizing cream (pleasant to most people) *vs* a basic cream. Although previous studies have shown that top-down attention can influence somatosensory processing in secondary and association areas (parietal area 7) with smaller effects in S1 (Johansen-Berg and Lloyd, 2000), we do not know of previous studies in which linguistic effects on affective touch have been investigated. The sight of touch can influence some areas involved in somatosensory processing including S1, S2, the inferior frontal gyrus and the parietal cortex (Blakemore *et al*., 2005; Schaefer *et al*., 2006), and given the possible importance of this in social cognition (Keysers *et al*., 2004), we also investigated where cognitive inputs that modulate affect can alter representations of the sight of touch.

Pleasant touch (and/or pain) have been shown to activate the anterior including pregenual cingulate and orbitofrontal cortex and the striatum (Rolls *et al*., 2003b), as have affective visual, taste and olfactory stimuli (Kringelbach *et al*., 2003; Rolls *et al*., 2003a; Kringelbach and Rolls, 2004; de Araujo *et al*., 2005; Kulkarni *et al*., 2005; Rolls, 2005), and we hypothesized that in these areas cognitive modulations of affective touch would be represented. Given previous findings (Johansen-Berg and Lloyd, 2000; Keysers *et al*., 2004; Blakemore *et al*., 2005; Schaefer *et al*., 2006), we also hypothesized that activations by touch and/or sight of the touch of the arm being rubbed, and possible effects of cognitive modulation, should be investigated in a priori areas of interest consisting of somatosensory and related areas (S1, S2, the insula and area 7).

One of the main experimental conditions used light touch produced by slowly rubbing the forearm with cream. This type of light touch is known to activate C fiber touch (CT) afferents and is pleasant (Olausson *et al*., 2002). To investigate the brain mechanisms by which CT afferents may contribute to pleasant touch, we included an additional condition (Hand) in which touch was being applied to glabrous skin on the hypothenar area of the hand, which is not a source of CT afferents, to test the hypothesis that some brain regions involved in affect such as the orbitofrontal cortex might be especially activated by the CT *vs* the non-CT touch.

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Table 1 Stimulus conditions

Conditions	Stimulus
Rubarm	cream is applied to subject's arm
Sight	video 1 of an arm being rubbed with a finger with moisturizing cream
Rubthin	'Basic cream' label and cream applied to arm
Rubrich	'Rich moisturizing cream' label and cream applied to arm
Sightthin	'Basic cream' label and video 1 of an arm being touched
Sightrich	'Rich moisturizing cream' label and video 1 of arm being touched
Thinlabel	'Basic cream' label only
Richlabel	'Rich moisturizing cream' label only
Sightnotouch	video 2 of finger moving above an arm and clearly not touching the arm
Hand	cream is applied to hypothenar area of the hand (glabrous skin)

In this investigation, we were interested in not only the effects of affective touch, but also how the brain interprets the sight of affective touch. To investigate this further, we included a comparison condition (Sightnotouch) for the sight of the affective touch stimulus in which the fingers were shown moving 1 cm above the arm and clearly not touching the arm. The visual stimulus was very similar in the control condition to the sight of touch condition, yet actual touch was clearly absent in the control condition. This differs from an earlier investigation in which the sight of a stick performing the touching was used (Keysers *et al.*, 2004), whereas we used the sight of interpersonal touch using a finger rubbing cream on the arm, which may with its relation to affiliative behavior be a stronger stimulus.

MATERIALS AND METHODS

Overall design

We examined cognitive influences on brain responses to the touch of a moisturizing cream being applied, or to the sight of the touch. To examine the effects of top-down cognitive influences originating from the language level, in some conditions the touch or the sight of the touch was accompanied by either the label 'Rich moisturizing cream' or 'Basic cream'. The instructions given to the subjects stated that we were interested in the factors that influence the pleasantness of creams, and in how rich thick and moisturizing the cream feels while being applied. They were informed that we were interested in what makes different types of cream pleasant when rubbed or seen to be rubbed on the forearm or hand area.

To measure the effects of the touch alone as a baseline/localizer condition without any cognitive modulation, a first condition was rubbing moisturizing cream on the forearm (rubarm in Table 1). To measure the cognitive effects of a word label on touch, the test conditions were the sight of a word label 'Rich moisturizing cream' (rubrich) or 'Basic cream' (rubthin) label whilst the subject was rubbed with the moisturizing cream. To measure the effects of the sight of touch alone as a baseline/localizer condition without cognitive modulation, a fourth condition was the sight of moisturizing cream being rubbed onto the forearm, with no actual cream delivered to the participant's arm (sight). To examine the effects of a word label on the sight of touch, further conditions were the sight of a word label 'Rich moisturizing cream' (sightrich) or 'Basic cream' (sightthin) displayed during the sight of a person's arm being rubbed (the video of the touch was always the same in the sightrich and sightthin conditions). The sight of the touch was shown to the subject using a video with identical timing to that used for the actual touch, and the video and labels were shown on a backprojection screen viewed by the subject through prisms whilst in the scanner. To allow comparison with the effects of the labels alone without touch or the sight of touch, and to show where top-down influences might be expressed even without any bottom-up (sensory) input, two additional conditions with the labels alone were included (Richlabel and Thinlabel conditions in Table 1). The additional hypotheses described in the 'Introduction' section were tested by the Hand and Sightnotouch conditions shown in Table 1 and also Figure 1.

Stimuli

The main touch stimulus consisted of a body lotion being rubbed onto the ventral surface of the left forearm. The cream was applied by the female experimenter with light (14 g), smooth and slow (2 cm/s) touch applied with one finger moving once up then down an 8 cm length of the forearm in 8 s. The experimenter was blind to whether word labels were being shown to ensure that the touch was the same independently of the cognitive condition. Only one cream was used in the experiment, allowing the effects of the word labels 'Rich moisturizing cream' and 'Basic cream' on a single type of touch to be investigated. A list of the 10 stimulus conditions is shown in Table 1.

Experimental design

During the fMRI experiment the participants made psychophysical ratings of pleasantness and richness on every trial, so that correlation analyses between the ratings and the brain activations could be performed. fMRI contrasts were performed as described in the 'Results' section to measure the effects of the word labels on the touch and on the sight of the touch, etc.

The experimental protocol consisted of an event-related interleaved design using in random permuted sequence the stimuli described above and shown in Table 1. This number of stimuli was chosen to be feasible given the number of repetitions of each stimulus needed and the length of time that subjects were in the magnet, but at the same time to allow the analyses described in the 'Introduction' section to be made. At the beginning of each trial, 1 of the 10 stimuli chosen by random permutation was presented for 8 s. If the trial involved a touch stimulus, this was applied to the forearm of the subject for 8 s. If it was a sight of touch trial,

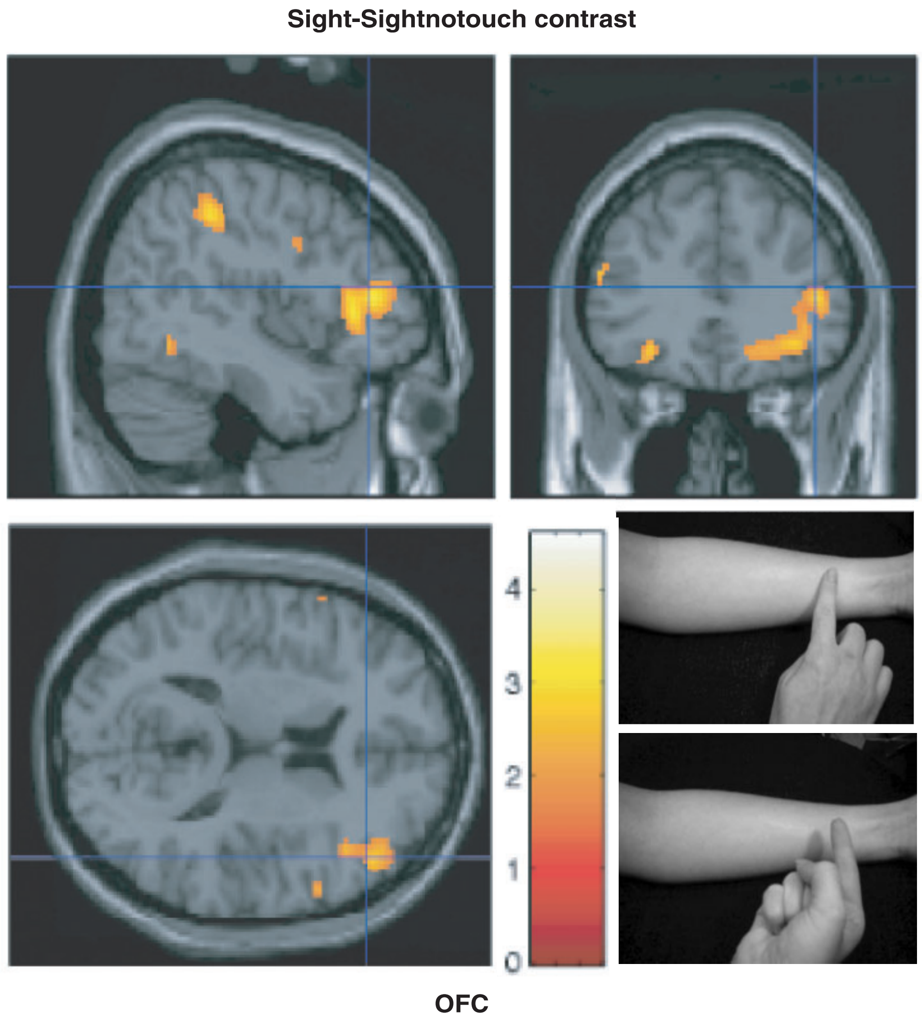


Fig. 1 The contrast Sight-Sightnotouch: a comparison of the effects of the sight of the arm being touched by an experimenter's finger *vs* the sight of the arm not being touched in that the experimenter's finger was moved inverted and 1 cm above the image of the arm (as shown in the inset image). Effects were found in the contralateral orbitofrontal cortex area 47 at [42, 30, −2] $Z = 3.45$ $P < 0.03$ and extended medially through much of the orbitofrontal cortex.

this was presented by a video lasting for 8 s of the same type of touch being applied to the forearm. The same video was used for all subjects. On appropriate trials (Table 1) the touch or the sight of touch was accompanied during the same 8 s by the word label 'Rich moisturizing cream' or 'Basic cream' presented on the backprojection screen. If a word label was not being shown, a green cross was shown on the screen instead. After a delay of 2 s, the subject was asked to rate each of the stimuli for pleasantness on that trial (with +2 being very pleasant and −2 very unpleasant), and for the perceived richness of the cream being applied on that trial (0 to +4, with 0 corresponding to very low richness and +4 to very rich). The ratings were made with a visual analog rating scale shown on the backprojection screen in which the subject moved the bar to the appropriate point on the scale using a button box. A trial was repeated for each of the 10 stimulus conditions shown in Table 1 in permuted sequence, and the whole cycle was repeated nine times. The instruction given to the subject was to rate the actual touch if one was given and if not then the imagined pleasantness or richness of the touch being shown in the video.

Subjects

Twelve healthy volunteers (all females between 18 and 30) participated in the study. Ethical approval (Central Oxford Research Ethics Committee) and written informed consent from all subjects were obtained before the experiment according to the Declaration of Helsinki. Each subject had a pre-testing session in the lab to inform the subject on what to rate in each condition and instruct them how to use the rating scales.

fMRI data acquisition

Images were acquired with a 3.0-T VARIAN/SIEMENS whole-body scanner at the Oxford Clinical Magnetic Resonance Centre (OCMR), where T2* weighted EPI slices were acquired every 2 s (TR = 2). We used the techniques that we have developed over a number of years (e.g. O'Doherty *et al.*, 2001b; de Araujo *et al.*, 2003) and as described in detail by Wilson *et al.* (2002) we carefully selected the imaging parameters in order to minimize susceptibility and distortion artefact in the orbitofrontal cortex.

Coronal slices (33) with in-plane resolution of 3×3 mm and between plane spacing of 4 mm were obtained. The matrix size was 64×64 and the field of view was 192×192 mm. Continuous coverage was obtained from +56 (A/P) to −50 (A/P). A whole brain T2* weighted EPI volume of the above dimensions, and an anatomical T1 volume with coronal plane slice thickness 3 mm and in-plane resolution of 1.0×1.0 mm was also acquired.

fMRI data analysis

The imaging data were analyzed using SPM2 (Wellcome Institute of Cognitive Neurology). Pre-processing of the data used SPM2 realignment, reslicing with sinc interpolation, normalization to the MNI coordinate system (Montreal Neurological Institute) (Collins *et al.*, 1994) used throughout this article, and spatial smoothing with a 8 mm full width at half maximum isotropic Gaussian kernel and global scaling. The time series at each voxel were low-pass filtered with a hemodynamic response kernel. Time series non-sphericity at each voxel was estimated and corrected for (Friston *et al.*, 2002), and a high-pass filter with a cut-off period of 128 s was applied. In the single event design, a general linear model (GLM) was then applied to the time course of activation where stimulus onsets were modeled as single impulse response functions and then convolved with the canonical hemodynamic response function (HRF, Friston *et al.*, 1994). Linear contrasts were defined to test specific effects. Time derivatives were included in the basis functions set. Following smoothness estimation (Kiebel *et al.*, 1999), in the first stage of analysis condition-specific experimental effects (parameter estimates, or regression coefficients, pertaining to the height of the canonical HRF) were obtained via the GLM in a voxel-wise manner for each subject. In the second (group random effects) stage, subject-specific linear contrasts of these parameter estimates were entered into a series of one-sample *t*-tests, each constituting a group-level statistical parametric map. The correlation analyses of the fMRI BOLD (blood oxygenation-level dependent) signal with given parameters of interest (e.g. the pleasantness ratings) were performed at the second-level through applying one-sample *t*-tests to the first-level subject-specific statistical parametric maps resulting from performing linear parametric modulation as implemented in SPM2. We report results only for brain regions where there were prior hypotheses as described in the 'Introduction' section, although in fact all the activations found in a whole brain analysis were within these areas for which there were prior hypotheses. Small volume corrections for multiple comparisons (Worsley *et al.*, 1996) were applied with a radius corresponding to the full width at half maximum of the spatial smoothing filter used. Peaks are reported for which $P < 0.05$ svc, and the exact corrected probability values (Worsley *et al.*, 1996) are given in Table 2. Further peaks are noted in the text if they are in the a priori predicted regions based on the prior hypotheses, survive a threshold of $P < 0.005$ uncorrected (unc), and are consistent with other activations found in this investigation.

RESULTS

Subjective ratings

The ratings of pleasantness and richness are shown in Figure 2, together with the finding that the cognitive word labels significantly modulated the pleasantness and richness ratings of touch and of the sight of touch.

Effects of touch on the forearm (rubarm condition)

First we identified the different brain areas activated in this study by touch to the arm used as a localizer, so as to provide reference locations when assessing where cognitive factors might influence activations to touch. In the rubarm condition (touch without any visual word labels) activations were found in the contralateral primary somatosensory cortex (S1), in S2/PV bilaterally, area 7, and insula from $y = 0$ to $y = -24$ as shown in Fig. 3. (The MNI coordinates, Z and P-values of the activations described throughout the results are shown in Table 2). The indication of activation in the primary somatosensory cortex S1 ([60, −18, 50] $z = 2.96$ $P = 0.002$ unc) was in a region very close to that at which the sight of the arm being rubbed produced activation (see below).

Effects of cognitive modulation on affective touch

This was tested by the contrast rubrich-rubthin (Figure 4), which is a comparison of the effects of touch when accompanied by the label 'Rich moisturizing cream' *vs* 'Basic cream'. Effects were found in the ipsilateral parietal cortex area 7 (Figure 4). As no significant effects were produced in area 7 by the word labels alone, the effect shown in Figure 4 may be interpreted as a modulation of the touch input being produced by the word label. Consistent with this, when for this identified part of area 7 the effects of the word label were subtracted from the contrast rubrich-rubthin, a significant difference was found ($P = 0.01$).

Further evidence on cognitive modulation comes from the correlations with the subjective ratings of pleasantness based on the rubrich and rubthin conditions, when the only factor altering the pleasantness was the cognitive label as the touch was identical. A negative correlation with pleasantness was found in the lateral orbitofrontal cortex, and in the contralateral somatosensory cortex S1. Pleasantness correlations within just this pair of stimuli were found in the striatum bilaterally (Table 2). An indication of a positive correlation with the richness ratings to this pair of stimuli was found in the pregenual cingulate cortex ([−8, 40, 14] $z = 2.93$ $P = 0.002$ unc). This is close to the region where a

Table 2 Coordinates for activations found in the different conditions, contrasts and correlations

Brain area	*x*	*y*	*z*	*Z*-score	*P*-value
Effects of touch on forearm: Rubarm condition (localizer)					
S2/PV	−60	−6	12	3.55	<0.01
Area 7	34	−38	74	3.44	<0.007
Insula	44	−16	14	3.83	=0.011
Insula	−40	−2	−12	4.14	<0.003
Effects of cognitive modulation on touch: Rubrich-rubthin contrast					
Area 7	−30	−42	42	2.82	<0.03
Effects of the sight of the arm being rubbed: Sight condition (localizer)					
S1	52	−18	60	4.17	<0.001
S1	38	−32	72	3.36	<0.03
lOFC	−28	34	−8	2.94	=0.05
OFC (47)	−48	34	4	2.68	=0.02
Effects of cognitive modulation on the sight of the arm being rubbed: Sightrich-sightthin contrast					
Pregenual cing/mOFC	−12	38	2	2.86	=0.04
OFC (47)	58	30	0	3.5	=0.005
Sightthin-sightrich contrast					
Ant Cing d	16	34	26	4.12	<0.001
Insula	−28	24	0	3.16	<0.05
lOFC	−40	34	−2	4.08	=0.005
Effects of rich label compared with thin label					
mOFC	−22	50	10	2.79	=0.05
+ Correlations with pleasantness: rubrich and rubthin conditions					
Striatum	−20	4	−6	3.58	=0.03
+ Correlations with pleasantness: sightrich and sightthin conditions					
mOFC	−14	50	−16	2.97	=0.02
V Striatum	−4	4	−14	2.95	≈0.05
− Correlations with pleasantness: rubrich and rubthin conditions					
lOFC	40	36	−16	3.28	<0.03
S1	38	−24	64	2.67	<0.04
− Correlations with pleasantness: sightrich and sightthin conditions					
lOFC	52	38	−2	3.29	=0.01
Ant cing d	4	36	36	2.89	=0.02
+ Correlations with richness: rubrich and rubthin conditions					
S1/S2	−56	−20	24	3.15	<0.03
+ Correlations with richness: sightrich and sightthin conditions					
Pregenual cing	−4	38	−4	3.08	=0.015
OFC (47)	42	48	12	3.13	=0.03
S1	54	−34	38	3.36	=0.04
− Correlations with richness: sightrich and sightthin conditions					
S1	56	−34	56	3.13	=0.028
Sight − Sightnotouch:					
OFC (47)	42	30	−2	3.45	<0.03
Area 7	−38	−52	52	2.79	=0.04
S1	64	−16	42	2.86	<0.05
Effects of touch on hand: Hand condition (localizer)					
S1	54	−20	58	3.31	<0.02
S2	58	−18	20	3.71	=0.002
Area 7	36	−32	74	4.67	<0.001
Insula	34	−22	22	4.49	<0.001
Comparison of touch to the arm with touch to the hand: Rubarm-hand contrast					
mOFC	26	50	−8	3.18	=0.035
Hand-rubarm contrast					
S1	40	−32	66	4.62	<0.001
Area 7	30	−52	58	4.07	=0.001
Ant cing d	−6	4	34	4.45	<0.001

Ant cing d, anterior cingulate, dorsal part; area 7, parietal cortex area 7; lOFC, lateral orbitofrontal cortex; mOFC, medial orbitofrontal cortex; OFC(47), orbitofrontal cortex area 47/12 on the inferior convexity; pregenual cing, pregenual cingulate cortex; S1, somatosensory cortex area S1; S2, somatosensory cortex area S2; PV, parietal ventral somatosensory area; V Striatum, Ventral Striatum.

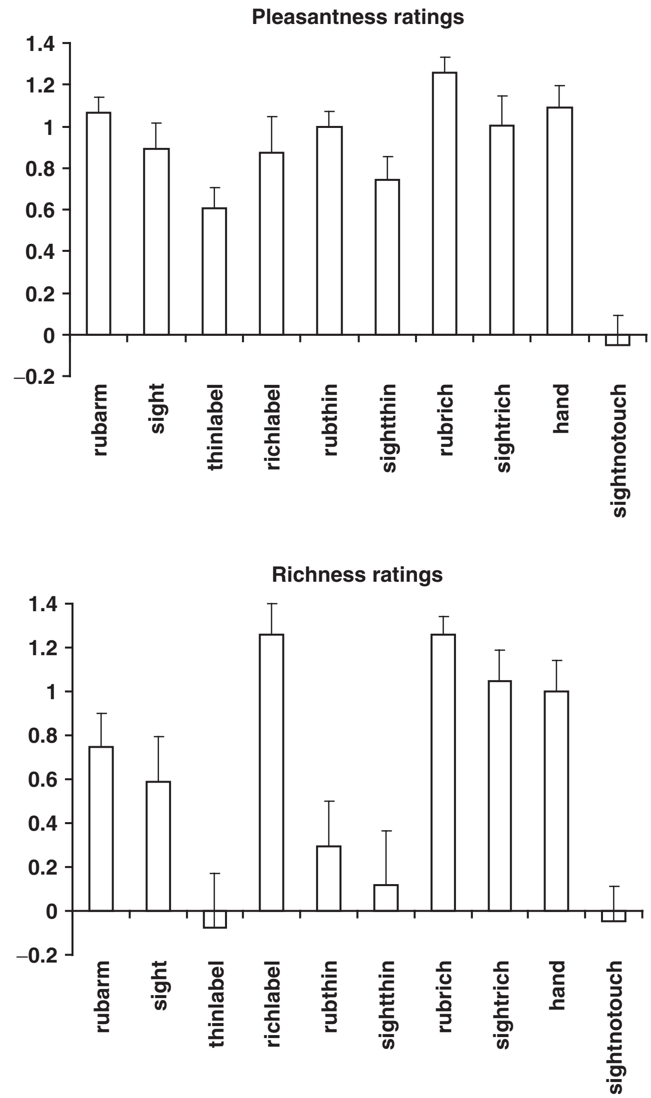


Fig. 2 The ratings of pleasantness and richness (means ± SEM). The pleasantness ratings were significantly different between the stimuli (one way within subjects ANOVA, $F[9, 99] = 15.45$, $P = 1.83 \times 10^{-15}$), as were the richness ratings ($F[9,99] = 16.74$, $P = 1.97 \times 10^{-16}$). *Post hoc* comparisons (LSD corrected) showed that the rubrich condition was rated significantly more pleasant than the rubthin condition ($P = 0.002$) and the sightrich condition was more pleasant than the sightthin condition ($P = 0.01$). The *post hoc* comparisons showed that the rubrich condition was rated significantly more rich than the rubthin condition ($P < 0.001$) and the sightrich condition was more rich than the sightthin condition ($P = 0.001$). For comparison, there was no significant difference in the subjective ratings between the richlabel and the thinlabel control conditions ($P = 0.157$).

positive correlation with richness was found based on the sightrich and sightthin conditions (Figure 5).

Effects of the sight of the arm being rubbed (sight condition)

In the sight condition used as a localizer, contralateral somatosensory cortex S1 was activated (Figure 6), and this region extended to include that activated by rubbing the arm. There was also activation in the part of the

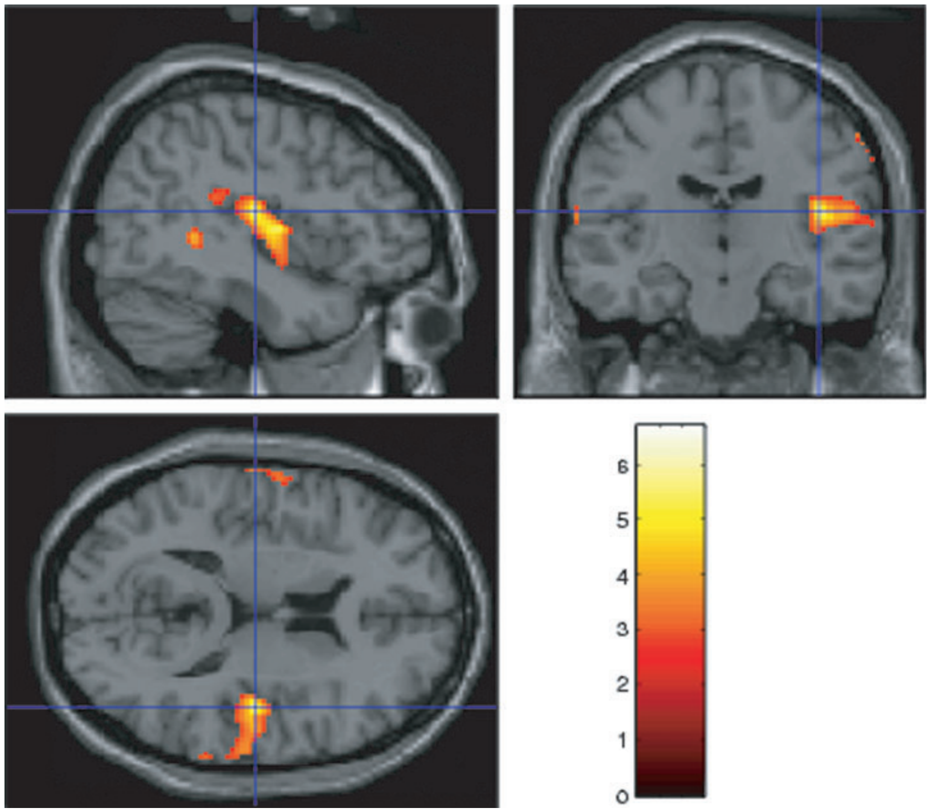


Fig. 3 Activations were produced by touch to the arm (rubarm condition) in the contralateral insula with peak at [44, −16, 14] $Z = 3.83$ $P = 0.01$. Activations were not produced in this region by the sight of the arm being rubbed.

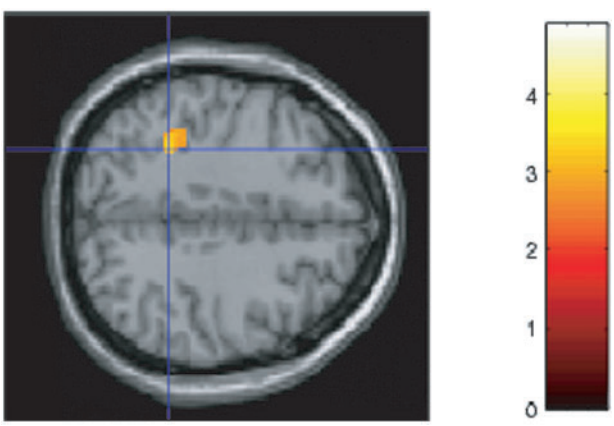


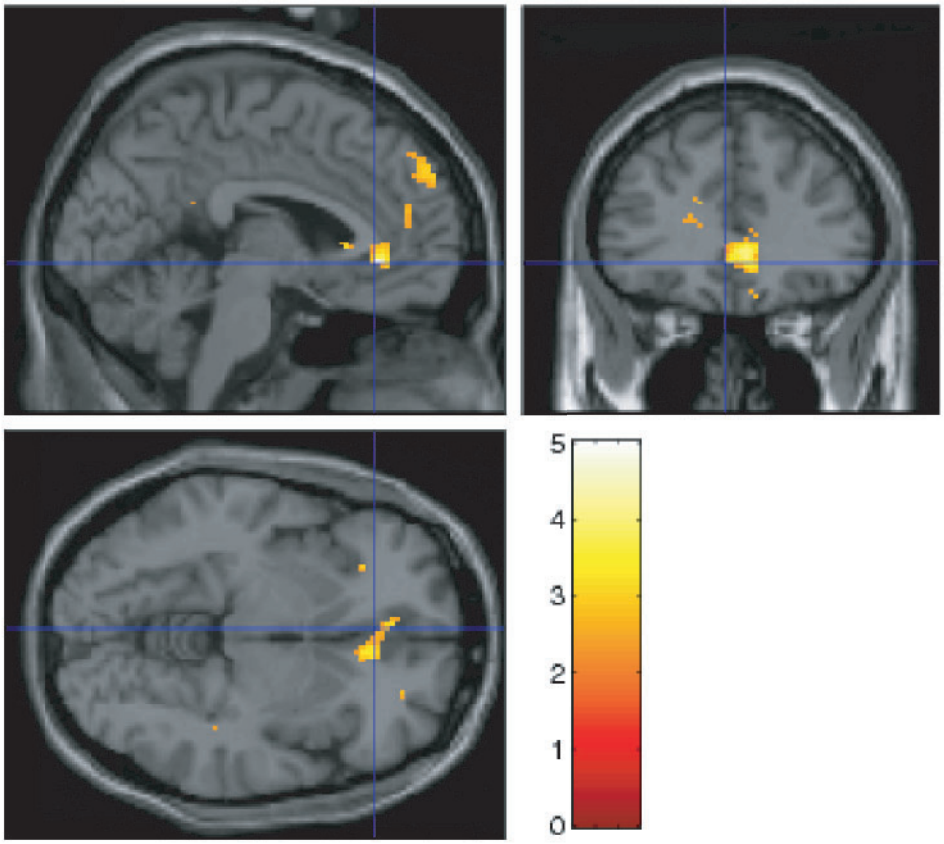
Fig. 4 Effects of cognitive modulation on touch. A contrast of the effects of touch when accompanied by the label 'Rich moisturising cream' *vs* 'Basic cream' showed effects in the ipsilateral parietal cortex area 7 at [−30, −42, 42] ($Z = 2.82$, $P < 0.03$) shown in this horizontal slice at $z = 42$.

orbitofrontal cortex which forms the infero-lateral convexity of the frontal lobe and which includes area 47/12 (Amunts *et al.*, 2004; Price, 2006) (abbreviated as OFC (47) in Table 2). Evidence supporting these findings is that the same three areas [OFC, OFC (47) and S1] are activated in the contrast sight-sightnotouch shown in Figure 1, and also parietal cortex area 7. Interestingly, activations were not produced by the sight condition in the insular somatosensory areas activated in the rubarm condition.

Effects of cognitive modulation on the sight of the arm being rubbed

This was tested by the contrast sightrich-sightthin, which is a comparison of the effects of the sight of the arm being rubbed when accompanied by the label 'Rich moisturizing cream' *vs* 'Basic cream'. Effects were found in the pregenual cingulate cortex extending into the orbitofrontal cortex, in regions close to those illustrated for correlations with pleasantness with the same two stimulus conditions in Figure 7. These effects were not due just to the word labels themselves, in that the condition richlabel-thinlabel produced no significant effect in this pregenual cingulate region. The effects were further shown not to be due just to the word label alone, in that for this identified region the contrast (sightrich-sightthin)−(richlabel-thinlabel) still showed effects ($P < 0.01$). Moreover, the top-down modulation by

Richness correlation
(Sightrich and Sightthin)



Pregenual cingulate cortex

Fig. 5 Correlations with the richness of the stimuli based on sightrich-sightthin were found in the pregenual cingulate cortex ([−4, 38, −4] $Z = 3.08$ $P = 0.015$).

the word label appeared to be multiplicative, as shown by the interaction where the factors were sightrich and sightthin *vs* richlabel and thinlabel ($Z = 2.43$, $P < 0.01$). The contrast sightrich-sightthin also produced effects in the orbitofrontal cortex (area 47), but these reflected a top-down effect of the word label alone, for similar activation was produced by richlabel-thinlabel (Table 2 and below), and no significant effects remained with the subtraction and interaction analyses described above. There was no significant effect in the insula of this contrast. Further evidence on the cognitive modulation of affective touch was found from the positive correlations with pleasantness based on the sightrich and sightthin conditions in the medial orbitofrontal cortex and the ventral striatum (Figure 7). [These correlations were significantly greater than those produced by the word labels alone (medial orbitofrontal cortex $P = 0.006$, ventral striatum $P = 0.007$) indicating that the effect was due to modulation by the word labels of brain activations to the sight of the arm being rubbed, and was not due to the word labels alone]. In addition, there was a positive correlation with the richness ratings based on the sightrich and sightthin conditions in the pregenual cingulate cortex (Figure 5). The correlation found with richness based on the rubrich and rubthin conditions in the pregenual cingulate cortex is thus very consistent with this result.

The opposite contrast, sightthin-sightrich, which might indicate brain regions where the thin label reveals activations related to less pleasantness or lack of richness, showed activations in the dorsal anterior cingulate and the insula. An effect was also found in the lateral orbitofrontal cortex ([−40, 34, −2]) in a region that corresponded contralaterally to that where there was a negative correlation with pleasantness. There was also a negative correlation with the richness ratings in the dorsal anterior cingulate cortex (Table 2).

Effects of rich label compared with thin label (richlabel and thinlabel conditions)

In this contrast richlabel-thinlabel the effects of the word label alone are examined. A significant effect was found in the mid orbitofrontal cortex. This is evidence for top-down effects of the cognitive word labels on the mid orbitofrontal cortex.

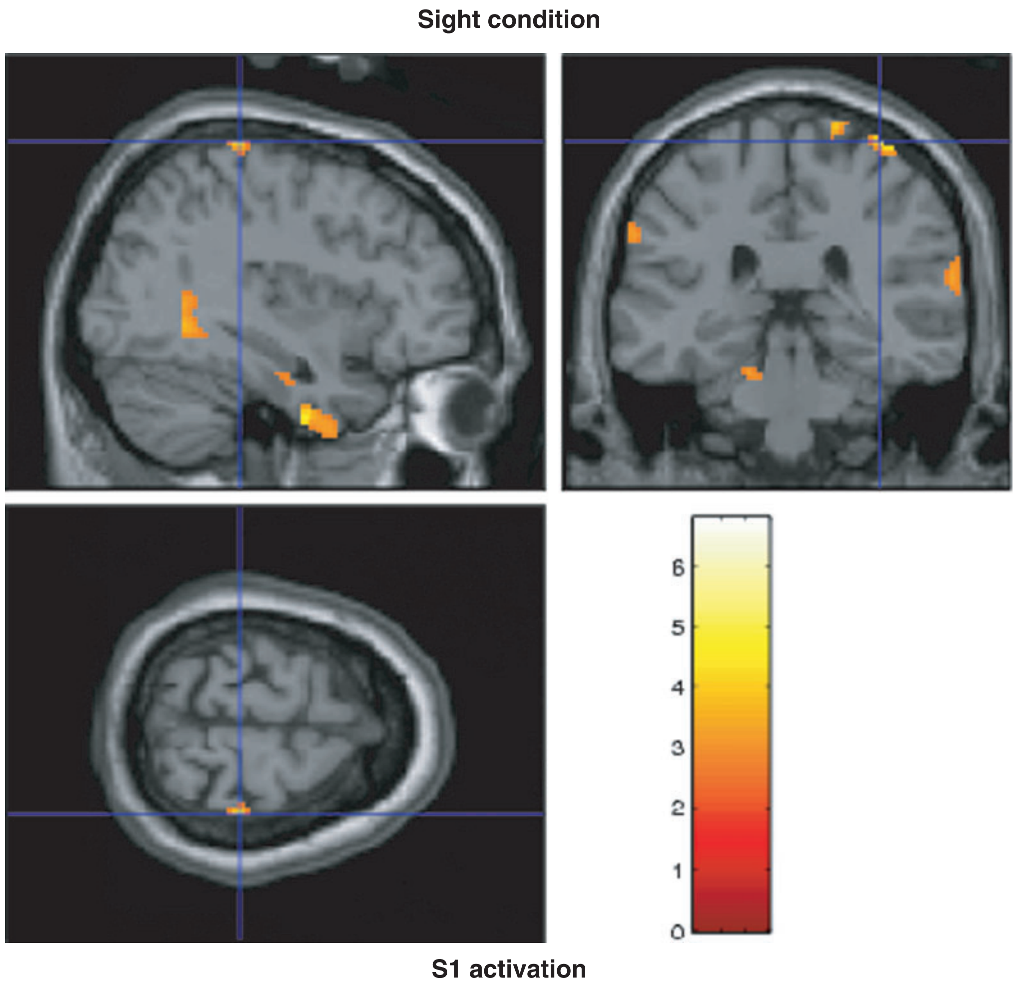


Fig. 6 Effects of the sight of the arm being rubbed (sight condition). The contralateral somatosensory cortex area S1 was activated [38, −32, 72] $Z = 3.36$ $P < 0.03$ in a region corresponding to that activated by rubbing the arm.

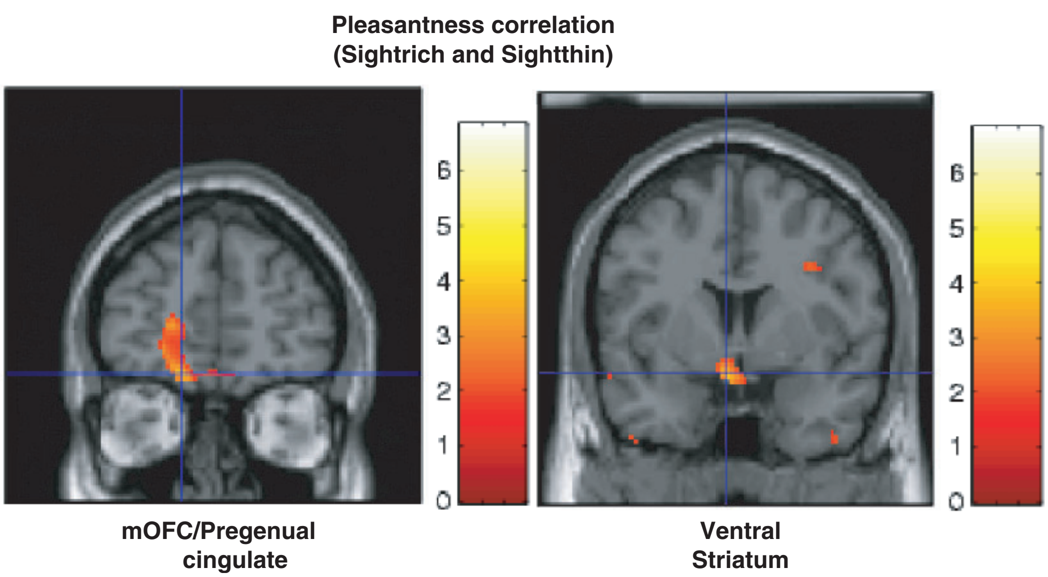


Fig. 7 Correlations with the pleasantness of the stimuli based on sightrich-sightthin were found in the medial orbitofrontal/pregenual cingulate cortex ([−14, 50, −16] $Z = 2.97$ $P = 0.02$) and ventral striatum ([−4, 4, −14] $Z = 2.95$ $P \approx 0.05$.

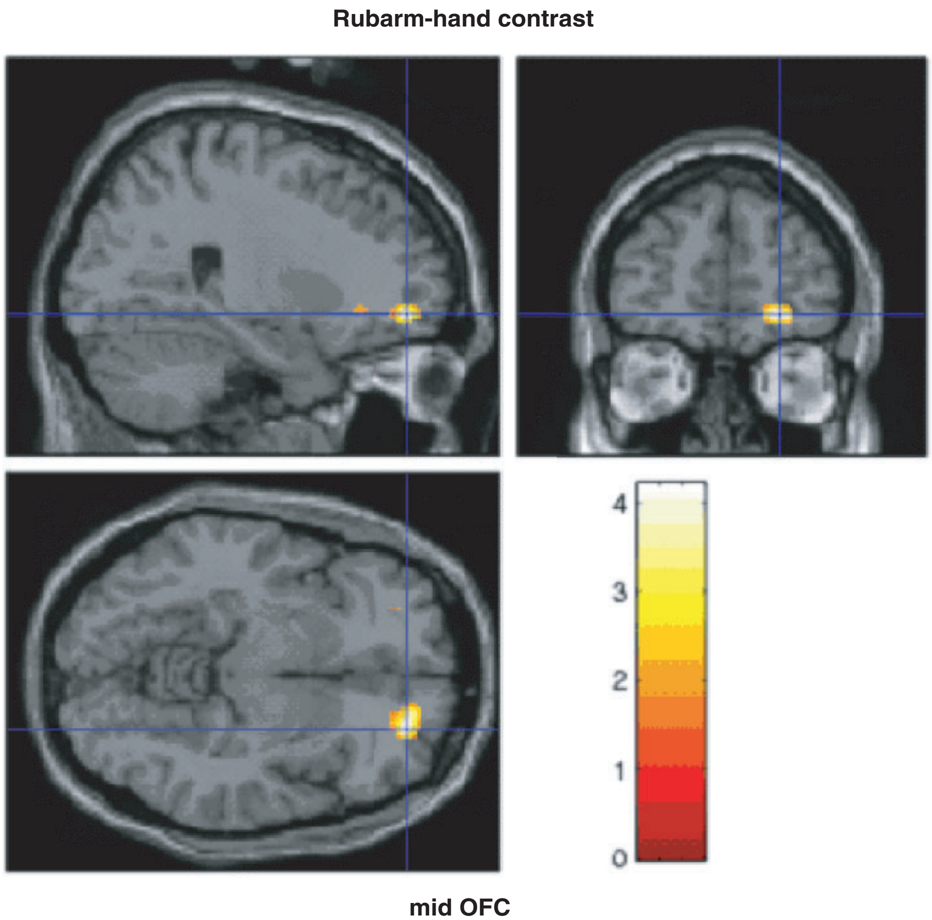


Fig. 8 The contrast rubarm-hand revealed activation in the mid-orbitofrontal cortex ([26, 50, −8] $Z = 3.18$, $P = 0.035$).

Comparison of touch to the forearm with touch to the hand

As light pleasant touch to hairy skin such as the forearm can activate CT afferents (Olausson *et al.*, 2002), it was of interest that the contrast rubarm-hand revealed activation in the mid-orbitofrontal cortex, as shown in Figure 8. For comparison, the contrast hand-rubarm activated many somatosensory areas, including S1, area 7 and dorsal cingulate cortex, due probably in part to the larger magnification factor of the hand than the arm (Table 2). Consistent with this, activations in the hand condition were found in S1, S2, area 7 and the insula.

DISCUSSION

Cognitive top-down modulation of touch and the sight of touch

We found that word labels (‘Rich moisturizing cream’ *vs* ‘Basic cream’) could modulate subjective ratings of the pleasantness and richness of touch (as shown in Figure 2), and influenced the representation of tactile inputs in the orbitofrontal cortex. For example, the ratings of pleasantness of the touch to the arm, which were modulated by the word labels were correlated negatively with activations in the lateral orbitofrontal cortex (Table 2). We also found that the word labels could alter the subjective ratings of the richness and pleasantness of the sight of touch (as shown in Figure 2), and influenced the representation of the sight of tactile stimulation in the pregenual cingulate cortex as shown by positive correlations of activations with the subjective richness ratings, and in the medial orbitofrontal cortex as shown by positive correlations of activations with the subjective pleasantness ratings (see Figures 5 and 7). This is further supported by the contrast sightrich-sightthin, which revealed effects in both the pregenual cingulate cortex and orbitofrontal cortex. Thus top-down cognitive effects modulate the affective representation of touch and the sight of touch in the pregenual cingulate cortex and orbitofrontal cortex. This is the first study in which the affective representation of touch in the brain has been shown to be modulated by cognitive effects at the word level. We emphasize that the physical stimulus in this investigation is identical when brain activations related to affect are being modulated by the word labels. Thus the investigation clearly shows a cognitive effect of the word labels on representations in the brain of the affective value of touch and the sight of touch. These new findings thus show that cognitive modulation influences affective representations of touch and/or the sight of touch in a pregenual/orbitofrontal cortex system in which another somatosensory stimulus, oral texture, is represented (de Araujo and Rolls, 2004); in which correlations with pleasantness ratings are found (Kringelbach *et al.*, 2003; de Araujo *et al.*, 2005; McCabe and Rolls, 2007); and in which pleasant touch produces activation (Rolls *et al.*, 2003b).

The activations in the ventral striatum, which receives from the orbitofrontal cortex, were also correlated with the pleasantness ratings in the sightrich and sightthin conditions, and thus shown to be influenced by top-down cognitive factors. This is of interest, for the ventral striatum is implicated in for example addiction (Robbins and Everitt, 1996; Everitt and Robbins, 2005; Baler and Volkow, 2006) and food craving (Rolls and McCabe, 2007), and our finding shows that even word-level cognitive effects can modulate how the ventral striatum responds to the same visual stimulus.

This investigation implicates different topological regions of the same brain structures in the negatively affective top-down modulations (as compared with the positively affective top-down modulation) produced by the cognitive word labels. A negative correlation with the pleasantness of touch as influenced by the labels was found in the lateral orbitofrontal cortex, a region shown in other studies to be activated by less pleasant stimuli including unpleasant odors, painful touch and losing money (O'Doherty *et al.*, 2001a; Rolls *et al.*, 2003a, b). A negative correlation with the inferred pleasantness of the sight of the touch as influenced by the word labels was found in the lateral orbitofrontal cortex and a dorsal part of the anterior cingulate cortex (regions in which a number of other unpleasant stimuli also produce activations), and consistently, the lateral orbitofrontal cortex and dorsal anterior cingulate cortex were activated by the contrast sightthin-sightrich. Thus top-down cognitive modulations can move affective representations of the same physical stimulus (touch, or the sight of touch) between different brain subregions that represent the positive (for example medial orbitofrontal and pregenual cingulate cortex) and negative affective value of stimuli. Analogous effects may be found with other stimuli. For example, a sentence stating that a person found money increased activations to a surprise face in the ventromedial prefrontal cortex, and a sentence stating that the person lost money increased activation to the same surprise face in the ventrolateral prefrontal cortex and amygdala (Kim *et al.*, 2004). Further, a positive word-level description of a pure taste stimulus, monosodium glutamate, increased activations in the pregenual cingulate cortex and ventral striatum; and of a flavor (monosodium glutamate with a vegetable odor) increased activations in the medial orbitofrontal cortex and ventral striatum (Grabenhorst *et al.*, 2007). In addition, affectively positive word level descriptors can increase activation to an olfactory stimulus in the medial orbitofrontal cortex and pregenual cingulate cortex (de Araujo *et al.*, 2005).

Some of these top-down effects were evident earlier in sensory processing (though without correlations with richness or pleasantness), in that for example the activations in the parietal cortex area 7 (Figure 4) and S1 to touch were modulated by the labels.

The sight of a stimulus where touch is implied

The contrast of seeing the arm being rubbed minus the control of seeing the finger moving but not touching the arm (sight-sightnotouch) showed effects in parietal area 7, S1 and the orbitofrontal cortex. This is of considerable interest, for it shows that these areas are activated particularly when the touch is made clear in the stimulus, that is when the fingers are seen to be rubbing the arm, and not just moving facing upwards 1 cm above the arm clearly not intending to touch it (Figure 1). The close visual control we use provides evidence that these systems are very sensitive to whether actual interpersonal touch is implied by what is seen. Using a similar visual control, activation of S2 was reported by the sight of touch in a previous study (Keysers *et al.*, 2004). Although in our study the activation of S2 did not reach significance, our finding of activations in another somatosensory area, S1 and in structures that receive somatosensory inputs such as the orbitofrontal cortex and area 7 may be related to the difference in the sight of the touch used in the two studies. In the previous study (Keysers *et al.*, 2004), the touch was produced by a stick, whereas in our study the sight was of interpersonal touch (one person rubbing cream with a finger on the skin of another person), which has implications for affiliative and social behavior, and may act as a more effective or at least somewhat different stimulus, especially for areas involved in emotion such as the orbitofrontal cortex (Rolls, 2005). Indeed, in our study the difference between the conditions indicated whether physical interpersonal contact was going to occur or not, and this could influence activations in all these areas.

Interestingly, in our investigation this contrast, sight-sightnotouch, also produced some activation in S1 (Figure 1), implying that backprojections from higher cortical areas (e.g. the parietal cortex) can influence S1 when the sight of actual touch is evident, and touch is therefore being imagined. In another study without such a close visual control condition (because the contrast was between the sight of a body and the sight of an object being touched), S1 activations were found when touch to a body but not touch to an object was being seen (Blakemore *et al.*, 2005). The visual input to the primary somatosensory cortex may have some useful functions, for TMS of the primary somatosensory cortex impairs the usual visual enhancement of tactile acuity (Fiorio and Haggard, 2005).

Insular somatosensory areas activated by actual touch but not by the sight of touch

However, in our study not all somatosensory areas were equal in being activated by the sight of an arm being touched, in that the insular somatosensory areas were not activated by the sight of the arm being touched, although these areas were activated by the touch itself. This leads us to suggest that the somatosensory areas in the mid/posterior insula are more concerned with real touch to one's own body, whereas in the sight condition it is less likely to be related to one's own body. Our finding is also consistent with evidence using a rubber hand that also suggests that insular activation may be related to body ownership (Tsakiris *et al*., 2007), whereas somatosensory cortex area S1 was activated when the touch was not attributed to the self. Moreover, Blakemore *et al*. (2005) showed that a synesthetic subject who felt touch whilst just observing touch had anterior insula activation whereas the control non-synesthetic subjects, who did not feel touch as they observed touch, did not have insular activation, again evidence for the insula being involved in recognition of touch to one's own body. In contrast to this mid and posterior insular region, more anterior parts of the insula showed cognitive effects of the word label on the sight of touch (with more activation to a less pleasant stimulus at [−28, 24, 0] as shown in Table 2). Effects of the sight of (painful) touch in the anterior insula have been described previously (Singer *et al*., 2004).

C fiber touch afferents

Light touch to hairy skin such as the forearm can activate CT afferents, and such afferents are thought not to be present in glabrous skin such as the palm of the hand (Olausson *et al*., 2002). Olausson *et al*. (2002) suggested that CT afferents provide a system that may underlie emotional and affiliative responses to light slowly-moving caress-like touch between individuals. Very interestingly in this context, the contrast rubarm-hand revealed activation in the mid-orbitofrontal cortex. The implication is that the orbitofrontal cortex might be especially activated in relation to CT afferents *vs* afferents from the glabrous skin.

In conclusion, this investigation provides the first evidence that top-down cognitive factors at the abstract level of words can influence the affective representation of touch, and the sight of touch, in brain regions such as the medial orbitofrontal and pregenual cingulate cortex and ventral striatum, where the cognitive input resulted in positive correlations with the pleasantness of the stimuli. Cognitive modulations were also found in the lateral orbitofrontal and dorsal anterior cingulate cortex where there were negative correlations with the pleasantness of the stimuli. These findings show that cognitive effects from the language level can reach down into the brain systems where the affective value of touch and the sight of touch are represented, with the important implication that cognition biases the actual representations of touch and the sight of touch. That is, the interaction between language-level cognition and affective touch is not left to high-level language related cortical areas, but the language-level cognition acts downwards on earlier cortical processing, probably by biasing competition, in areas such as the orbitofrontal cortex and pregenual cingulate cortex (Rolls, 2008).

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