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Rough primes and rough conversations: Evidence for a modality-specific basis to mental metaphors

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Abstract

How does our brain organize knowledge? Traditional theories assume that our knowledge is represented abstractly in an amodal conceptual network of formal logic symbols. The theory of embodied cognition challenges this view and argues that conceptual representations that constitute our knowledge are grounded in sensory and motor experiences. We tested this hypothesis by examining how the concept of social coordination is grounded metaphorically in the tactile sensation of roughness. Participants experienced rough or smooth touch before being asked to judge an ambiguous social interaction. Results revealed that rough touch made social interactions appear more difficult and adversarial, consistent with the rough metaphor. This impact of tactile cues on social impressions was accompanied by a network including primary and secondary somatosensory cortices, amygdala, hippocampus, and inferior prefrontal cortex. Thus, the roughness of tactile stimulation affected metaphor-relevant (but not metaphor-irrelevant) behavioral and neural responses. Receiving touch from a rough object seems to trigger the application of associated ontological concepts (or scaffolds) even for unrelated people and situations (but not to unrelated or more general feelings). Since this priming was based on somatosensory brain areas, our results provide support for the theory that sensorimotor grounding is intrinsic to cognitive processes.

Keywords: somatosensory cortex; embodiment; touch; social; fMRI

Introduction

In the traditional understanding our knowledge is represented abstractly in a supramodal conceptual network of formal logic symbols. The theory of embodied cognition challenges this view and claims that cognitive representations are based in sensory and motor experiences, forming a "perceptual symbol system" (Lakoff and Johnson 1999; Gallese and Lakoff, 2005; Barsalou 2008). Following this theory mental processes involve simulations of body-related perceptions and actions. Therefore, the theory argues that the retrieval of conceptual meaning involves a partial re-enactment of sensory and motor experiences. This may be explained by early experiences with the physical world, which structure our later understanding or representation of more abstract concepts (Williams et al. 2009; Ackerman et al. 2010; Meier et al. 2012). Others emphasize that we are "evolved from creatures whose neural resources were devoted primarily to perceptual and motor processing" (Wilson 2002).

Focusing in particular on the role of metaphors in human thought, numerous behavioral experiments provided support for this theory of embodied cognition (e.g., Zhong and Leonardelli 2008; Ackerman et al. 2010; Lee and Schwarz 2010a,b). For example, the abstract concept of importance has been shown to be grounded in bodily experiences of weight. Thus, holding a heavy clipboard made job candidates appear more important (Jostmann et al. 2009; Ackerman et al. 2010). Furthermore, it has been shown that basic tactile sensations have an impact on higher social cognitive processing in dimension- and metaphor-specific ways. For example, roughness is metaphorically associated with the concepts of difficulty and harshness (e.g., "having a hard day"). Ackerman et al. (2010) examined the link of this metaphor with sensory processing. Participants were instructed to complete a five-piece-puzzle, either in a version with pieces covered in rough sandpaper (rough condition) or a version with the pieces uncovered (smooth condition). Subsequently, they were asked to read a passage describing an ambiguously valenced social interaction and to answer questions regarding the nature of this interaction. Participants who completed the rough puzzle rated the interaction as less coordinated (more difficult and harsh) than participants who performed the same task but with smooth parts. Hence, the experience of rough objects made social interactions appear more difficult. Since there was no effect for a set of questions asking for relationship familiarity, Ackerman et al. (2010) concluded that roughness specially changed evaluations of social coordination consistent with a "rough" metaphor, but did not make the interaction seem more generally impersonal.

Recent advances in neuroimaging now allow testing the hypothesis that our thoughts and feelings are grounded in bodily interaction with the environment in a new way. The current study aimed to test the theory of embodied cognition by examining brain responses of participants with functional magnetic resonance imaging (fMRI) in a paradigm on the touch-related metaphor of roughness. Roughness is metaphorically associated with the concepts of difficulty, adversary, and harshness. Based on experiments by Ackerman et al. (2010) we hypothesized that tactile experiences with rough objects elicit a "haptic mindset", which may trigger the application of associated concepts such as difficulty and adversary (in contrast to more general feelings) when assessing a social interaction, consistent with the "roughness metaphor". An engagement of the somatosensory cortices in this process would provide support for the assumptions of the embodiment theory.

Materials and Methods

Participants

Twenty participants (ten females) with a mean age of 26 years (range 23 – 39) took part in the study. All participants were right-handed native German volunteers with no neurological or psychiatric history. The participants gave informed consent to the study, which adhered to the Declaration of Helsinki and was approved by the local human subjects' committee.

Procedure

Participants were explained that the study would involve two separate experiments: an experiment in order to examine neural correlates of different touch and an experiment to investigate neural correlates of social judgments.

We used a two-factorial experimental design. The first factor described the tactile priming, which was either rough by applying touch with sandpaper, smooth by using a smooth paintbrush, or was omitted (no stimulation). The second factor was the set of questions. One set of questions addressed the social coordination quality, the other set of question was asking for relationship familiarity.

While lying in the scanner the participants received passive tactile stimulation (rough, smooth, or no touch) for ten seconds. After five seconds participants were prompted with a screen describing an ambiguous valenced social interaction. The presentation of the scenario lasted for 19 seconds, while the first five seconds overlapped with the tactile stimulation. These social interactions were oriented to the experiments of Ackerman et al. (2010) and included both positive (e.g., kidding around) and negative components (e.g., sharp words), making the whole scenario ambiguous in its meaning (analogue to Kay et al., 2004). For example, participants read the following scenario: “>>Hello, have you seen the pictures of our last Christmas party? What is your girlfriend thinking of this? Well, she doesn't have to know everything!<< >>Oops, what am I doing there?<< >>Well, you seem to have fun!<< >>That’s what it looks like, he he. Hey, don't show this to someone else!<< >>Don’t worry, I won’t tell her.<< >>Has someone taken these pictures with some intentions behind? What’s all this crap?<< >>Calm down, look, I just deleted them!<<.”

After a break of four seconds we asked the participants about the nature of this interaction. One set of questions addressed the social coordination quality (was the interaction adversarial or friendly, competitive or cooperative, a discussion or an argument), for example: “What do you think, was this interaction adversarial or friendly? Friendly: right buttons. Adversarial: left buttons”. The other set of question was asking for relationship familiarity (closeness of relationship, business or casual interaction style, relationship of the agents). The latter set was applied in order to test if the priming effect would extend to a theoretically unrelated measure. Participants used a key with four buttons (Likert-scale ranging from +2 to -2) to assess the scenarios. Before the experiment they were explained that they could weight their responses from moderate (inner buttons) to extreme (outer buttons). Use of right and left buttons were randomized over the scenarios. They were allowed to spend up to 17 seconds to respond (earlier responding did not automatically start the next trial). In order to collect comparable parts of the decision process for each participant, we decided to measure brain activity in a time window around the button press. Thus, condition-related activity was measured using an individual “floating” time window of eight MR images surrounding (four before, one during, and three after) each point of response (analogue to Greene et al., 2001).

Using the responses of the participants we created a social coordination index (SCI), which included the mean of all three social coordination assessments. Furthermore, we calculated the mean of all three assessments of relationship familiarity, resulting in a relationship familiarity index (RFI).

The scenarios were based on a pre-study to match ambiguity needs. In this pre-study students were asked to evaluate a sample of scenarios with respect to its overall emotional valence by using a nine-point Likert-scale ranging from very positive to very negative. Only those scenarios that were rated as ambigous were included in the study.

While lying in the scanner, a total of 96 scenarios was presented to each participant. Each scenario was repeated six times. Thus, each scenario was once preceded by a rough, by a smooth, or by no tactile stimulation (random order within subjects). In addition, each scenario was once followed by questions from the SCI set and once from the RFI set. There was only one question after each scenario. The order of presentation of the scenarios as well as the order of the subsequent questions was randomized within subjects and between subjects. There were at least five scenarios between repetitions of a scenario.

Tactile stimulation was applied to the right hand. Participants were required to press buttons with their left hand in order to assess the interactions.

Visual images were back-projected to a screen at the end of the scanner bed close to the subject’s feet. Subjects viewed the images through a mirror mounted on the birdcage of the receiving coil. The experiment consisted out of three runs. Each run included all conditions.

After scanning the participants were probed for suspicions concerning the experimental hypotheses.

This study adopted a paradigm introduced by Ackerman et al. (2010), which described a social psychology experiment. In order to employ this paradigm within a neuroimaging context, we needed to change it in several points. Thus, since we tried to demonstrate the effect as a within-subjects effect, we used a relatively high number of scenarios for each participant. Furthermore, we applied passive tactile stimulation. In addition, we included a second control condition (no tactile stimulation).

FMRI Data Acquisition and Analysis

Functional scans were acquired by using a 1.5 T scanner (General Electrics Signa LX, USA; gradient echo T2-weighted echo-planar images; TR = 2 sec, TE = 35 ms, flip angle = 80 degrees, FOV = 20 mm). For each subject, data were acquired in three scan runs. Functional volumes consisted of 23 slices. Each volume comprised 5 mm slices (1 mm gap, in plane voxel size 3.125 x 3.125 mm). For anatomical reference a high-resolution T1-weighted structural image was collected (3D-SPGR, TR = 24 ms, TE = 8 ms).

FMRI data was preprocessed and analyzed using the Statistical Parametric Mapping Software (SPM5, Wellcome Department of Imaging Neuroscience, University College London, London, UK). For each subject the fMRI scans were realigned to correct for inter-scan movement, using sinc interpolation and subsequently normalized into a standard anatomical space (MNI, Montreal Neurological Institute template), resulting in isotropic 3 mm voxels. The scans were then smoothed with a Gaussian kernel of 6 mm full-width half maximum.

Statistical parametric maps were calculated using multiple regressions with the hemodynamic response function modeled in SPM5. Data analyses were performed at two levels. We examined data on the individual subject level by using a fixed effects model (all three runs concatenated for each subject). Then, the resulting parameter estimates for each regressor at each voxel were entered into a second-level analysis with the random effects model. To examine brain responses when participants received touch we computed statistical contrasts (t tests) for rough stimulation (sandpaper) relative to rest, smooth stimulation (paintbrush) relative to rest, and both rough and smooth stimulation relative to rest. In order to reveal brain responses during the judgment process we calculated an ANOVA for repeated measurements with the factors priming (rough, smooth, none) and set of questions (social coordination, relationship familiarity). Subsequently, statistical contrasts (t tests) were performed to examine cortical activation associated with priming conditions for the different set of questions. Finally, to further investigate if regions that are specific to preprocessing tactile sensations subserve the priming effect, we examined priming effects on the judgments masked with the results of the contrast receiving rough and smooth touch relative to rest.

Scores of participants' judgments were tested for possible correlations (Pearson) with the parameter estimates for voxels in the somatosensory region of interest (maximum peak in left SI). In addition, we tested possible correlations with participants' judgments for SII, IFG, IPC, hippocampus and amygdala.

We report regions that survived correction for multiple comparisons over the whole brain (at $p < 0.05$, family-wise (FDR) correction). To describe the anatomical regions we used the SPM anatomy toolbox (Eickhoff et al., 2005).

Results

Behavioral results

None of the participants reported any suspicions with respect to our experimental hypotheses.

Behavioral results revealed a significant interaction between way of tactile priming and the set of questions (ANOVA interaction with factors condition and set of questions, $F(2,38) = 3.77$, $p < 0.05$). Post hoc t-tests demonstrated effects for tactile priming of the social coordination set. Rough priming revealed significant lower scores on the social coordination scale compared with smooth priming (rough priming of social coordination judgment, mean and standard deviation: 2.61 ± 0.39; smooth priming: 2.71 ± 0.39; $t(19) = 2.41$, $p < 0.05$, two-sided, Bonferroni corrected for multiple tests) or with no priming (no priming: 2.74 ± 0.39; $t(19) = -2.35$, $p < 0.05$; no effect for smooth priming relative to none priming ($t(19) = -0{,}49$, p = n.s.) (see Fig. 1). Since there were no effects for tactile priming of the relationship familiarity set we concluded that tactile priming with rough objects specifically made social interactions appear less coordinated (more harsh, difficult and adversarial), but did not make the scenario seem more generally impersonal (similar to Ackerman et al., 2010).

Analysis of the reaction times revealed no significant effects (social coordination: rough priming: 5.55 ± 1.37 s, smooth: 5.37 ± 1.31s, none: 5.96 ± 1.73 s; familiarity relationship: rough: 5.42 ± 0.97 s, smooth: 5.46 ± 1.16 s, none: 5.52 ± 1.06 s; ANOVA with factors condition and set of questions: no significant main effects or interactions).

Insert Figure 1 about here

FMRI results: Brain responses while participants received touch

Brain responses during passive touch applied by both a smooth paintbrush and rough sandpaper revealed activation in left primary somatosensory cortex (SI) and left secondary somatosensory cortex (SII) (rough + smooth touch relative to rest, see Fig. 2). The contrasts rough touch relative to rest as well as smooth touch relative to rest revealed comparable activation in left SI and left SII. The statistical contrast for rough relative to smooth touch and smooth relative to rough touch failed to reveal any significant activation (at $p < 0.05$, FDR corrected). Thus, brain responses to rough and smooth touch showed no significant differences in brain activations.

Insert Figure 2 about here

FMRI results: Brain responses while participants judged the social interactions

Brain responses during judging interactions revealed involvement of somatosensory brain areas (SI, SII), inferior frontal gyrus (IFG), hippocampus, amygdala, premotor cortex and inferior parietal cortex (IPC) (ANOVA interaction with factors condition and set of questions). Post hoc t-tests with respect to social coordination assessments for rough relative to no priming demonstrated involvement of SI, SII, IFG, hippocampus, amygdala, premotor cortex, and IPC (rough > no priming, for SCI, FDR corrected; see Fig. 3 and Table 1). Comparison of rough relative to smooth priming showed engagement of SI, premotor cortex, IFG, hippocampus, and amygdala (rough > smooth priming, for SCI, FDR corrected). Smooth relative to rough or relative to no priming failed to reveal significant activations (for SCI; at $p < 0.05$; FDR corrected; see Table 1). Post hoc t-tests with respect to RFI questions (control condition) failed to show significant activations (rough > smooth priming, rough > no priming, smooth > rough priming, smooth > no priming, for RFI; at $p < 0.05$; FDR corrected).

A comparison between rough priming for SCI relative to rough priming for RFI was accompanied by activations of SI, premotor cortex, IPC, and IFG (FDR corrected, see Table 2). For smooth priming, the analogue contrast revealed no significant voxels. Hence, the demonstrated metaphor-specific impact of rough priming on social judgment seems to rely on a network of brain regions including sensorimotor brain regions, IFG, IPC, hippocampus, and amygdala.

In order to better understand if regions that are specific to process tactile sensations subserve the tactile priming effect, we masked our analysis with the results of the contrast tactile stimulation (rough + smooth touch) relative to rest (at < 0.05, FDR corrected). Fig 4 shows for SCI judgments that rough relative to none or relative to smooth priming engaged brain areas that were also involved during receiving the tactile primes (SI and SII). In contrast, Table 3 depicts that control comparisons (smooth relative to rough priming, smooth relative to no priming) failed to reveal any significant activation in SI or SII. Furthermore, Tables 3 and 4 and Fig 5 show that this results accounts only for the SCI judgments, RFI judgments (control condition) did not show any somatosensory activations.

Brain responses in SI for the contrast rough relative to no priming were significantly linked with the bias to assess the interaction less coordinated ($r = 0.69$, $p < 0.005$, Pearson, two-sided, see Fig. 4; correlation between signal change in SI and decreased

SCI assessments). Brain responses in SI for the contrast rough relative to smooth priming revealed a similar significant correlation with the behavioral bias to perceive the scenarios less coordinated and more harsh and adversarial ($r = 0.61$, $p < 0.005$, see Fig 4; correlation between signal change in SI and decreased SCI assessments). Correlations for SII activity failed to show significant relationships with SCI judgments. Furthermore, activation in IFG, IPC, hippocampus, and amygdala showed no significant correlations with SCI assessments.

Insert Figure 3 about here

Insert Figure 4 about here

Insert Figure 5 about here

Insert Table 1 about here

Insert Table 2 about here

Insert Table 3 about here

Insert Table 4 about here

Discussion

The current study examined brain responses of participants when being asked to judge ambiguous interactions. Tactile priming with a rough stimulus (compared with smooth or no priming) resulted in a assessing the interaction as more harsh, difficult and adversarial, but did not make the scenario seem more generally impersonal. This bias is in accordance with a rough metaphor of social coordination and was accompanied by an active network of brain responses including sensorimotor brain areas, hippocampus, amygdala, IPC and IFG.

The behavioral responses are in line with the results of Ackerman et al. (2010). Experiencing rough objects made social interactions appear more difficult. Whereas Ackerman et al. (2010) report these results as the outcome of a social psychology experiment, we here demonstrate that this effect can also be operationalized for the purpose of an fMRI-study, which usually requires many repetitions and includes less participants.

We hypothesized that the effect originally reported by Ackerman et al. (2010) involves in particular the somatosensory regions, which would provide neurophysiological evidence for the embodiment theory. Our results confirm this hypothesis. Rough tactile priming (relative to smooth or no priming) was associated with activation in somatosensory brain areas, accompanied with an involvement of hippocampus, amygdala, IPC, and IFG. Moreover, somatosensory activation correlated highly positive with the degree participants judged the interaction as being harsh, difficult, and adversarial. This network was involved when being asked to judge the interactions with respect to its social coordination, but not when participants were instructed to relate the familiarity of the agents. Hence, it was closely associated with the roughness metaphor.

The role for somatosensory brain regions in this metaphor-specific tactile priming of social judgments strongly supports the embodiment theory, which postulates that the retrieval of conceptual meanings (metaphorical knowledge) includes a re-enactment of corresponding sensory experiences. But how may this re-enactment work? It has been demonstrated that cells in in the somatosensory cortex may act as a transient storage site for tactile (Harris et al. 2002) and even for visual and acoustic information (Zhou and Fuster 1996; Zhou and Fuster 2000). Anatomic studies in monkeys revealed that the somatosensory cortices are linked with prefrontal cortices via the medial temporal lobe for long-term encoding (Burton and Sinclair 2000). The IFG has been related to the evaluation of semantic information (e.g., Heim et al. 2009) and to the storage of rules learned in a social context (Monfardini et al. 2008). In addition, numerous studies relate the IFG with tactile memory (e.g., Romo et al. 1999; Kelly et al. 2007; Aukszutlewicz et al. 2012). Together with somatosensory brain areas the IFG seems to code the knowledge (the metaphor) that roughness is associated with the concepts of difficulty and harshness. SI and IFG may be linked via memory structures in the medial temporal lobe (hippocampus, amygdala), which have been suggested to bind distributed activated sites in the neocortex that represent a whole memory (e.g., Squire et al., 1993). The IPC has been related to various social cognition tasks. In particular, the temporo-parietal junction area is known to be related to understanding other people and reasoning about the content of mental states (e.g., Saxe and Kanwisher, 2003; Harenski et al., 2010).

But why are conceptual representations such as “roughness” so closely linked to tactile experiences? From infancy, touch on our hands is always two-folded: we use it to acquire information, but also to manipulate our environment (Gallace and Spence 2010). Given that touch may be the first sense to develop, physical touch experiences may establish an ontological scaffold for the development of conceptual and metaphorical knowledge (Williams et al., 2009; Ackerman et al., 2010; Meier et al., 2012). Thus, scaffolding or embodiment might be grounded in the physical substrate of early touch experiences, suggesting that tactile sensations might be crucial for the development of social bonds in early childhood and later application of this then scaffolded or embodied knowledge.

And why it is so easy to manipulate our social perception? According to the theory of embodiment similar areas that were engaged during the creation of the scaffold should be involved in the later application of the concept or metaphor (Meier et al., 2012; Wilson, 2002). Thus, activating similar touch experiences may result in an activation of the metaphor-specific bias. Since our results demonstrated that this embodied knowledge seems to be represented even in primary cortex areas, incidental and unconscious manipulations via tactile experiences appear to be very easy.

Recent studies similarly examining embodied metaphors support our results. Bargh et al. (2008) demonstrated that experiencing physical warmth, e.g., holding a cup of hot (versus iced) coffee make it likely to judge a person as having a “warm” personality. Kang et al. (2011) employed fMRI to examine the neural underpinnings of this link between physical and social warmth. They demonstrated that insular regions sensitive to physical warm perceptions are also engaged during manipulations of trust in the context of a decision-making game. Thus, physical temperature influenced human decision-making associated with an engagement of the insula. Similarly, Eisenberger et al. (2003)

reported overlapping activation in anterior cingulate cortex for processing physical and psychological pain.

Both the Kang et al. (2011) as well as our own study demonstrate that embodied metaphor effects are grounded in neurophysiological processes. Whereas Kang et al. (2011) report a functional overlap in the processing of information related to physical and psychological warmth in the left insula, our study shows that the roughness metaphor links physical touch and psychological impressions of a rough conversation in SI. In the traditional view the map in SI represents physical touch on the body surface. Recent studies in the last two decades challenge this view and suggest a more complex role for SI. For example, an increasing body of evidence demonstrates vicarious activation in SI when witnessing pain or simple touch on other's bodies in the absence of any real touch (e.g., Keysers et al., 2004; Bufalari et al. 2006; Ebisch et al., 2008). Based on these results, a role for somatosensation in social perception has been suggested, which might point to simulation processes in the observer's SI (Gallese et al., 2003, 2005; Keysers et al. 2010). Recent work also link mirror-like responses in SI with interindividual differences in empathy (Gazzola et al. 2006; Schaefer et al. 2012). The results of the current study extend the research on mirror-like responses in SI, suggesting that activation in primary somatosensory areas may include higher-order cognitions including psychological concepts such as the roughness metaphor.

Our results provide evidence for tactile priming with rough touch, but fail to demonstrate analogue effects for smooth touch. Several reasons might explain this lack of effect. First, the smooth tactile primes we used in the current experiment might not have affected the roughness-smoothness metaphor. Although we used a particular smooth paintbrush another tactile stimulation (for example, satin) might have been more successful. Second, there may not be a smoothness counterpart of the roughness metaphor. While our study as well as the experiment by Ackerman et al. (2010) provided behavioral evidence for a priming effect of rough tactile experiences on subsequent evaluations of social coordination, no experiment has shown that this effect also works for smooth tactile experiences (Ackerman et al. worked with pieces of a puzzle covered with rough sandpaper relative to pieces uncovered, but there was not a particular smooth condition). Further studies are needed to better understand which haptic experiences influence social impressions.

The present study examined brain responses in a time window around a judgment decision. Thus, we did not trace the whole complex decision making process which may start much earlier. Based on this limitation, it remains unclear if the somatosensory cortex is directly involved in the process of assessing a social interaction, or whether a tactile stimulus can somehow evoke a haptic mindset, triggered by a tactile sensation. However, fMRI has a limited temporal resolution, making it difficult to separate different processing stages of decisions (Hauk and Tschentscher, 2013). Future research is needed to disentangle which aspect in the complex decision making process are affected by touch sensations.

Several previous studies reported different activation in somatosensory cortices and other brain regions when comparing gentle or smooth with rough or unpleasant touch (e.g., Francis et al., 1999). However, comparing brain responses while experiencing rough relative to smooth touch in our study yielded no significant activation. We speculate that in the present study these differences were too small to reach the level of significance.

In sum, our findings demonstrate that basic tactile sensations have an impact on higher social cognitive processing in metaphor-specific ways and that the neural underpinnings of this bias involve SI, IFG and memory related structures. Thus, physical environment cues may influence people's judgments and decisions. The results show how an evolutionary physical concept such as touch is functionally related on a neural level to a metaphorically linked psychological concept (Williams and Bargh 2008; Anderson 2010; Kang et al. 2011).

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Figure legends

Figure 1: Effects of tactile priming on social impressions. Perceived social coordination was significantly lower when participants were primed with a rough stimulus (sandpaper) compared with a smooth prime (paintbrush) or no prime.

Figure 2: Statistical maps showing brain activation while participants were passively touched by a smooth paintbrush and rough sandpaper (A). (B) displays BOLD responses to touch by a smooth paintbrush alone. (C) depicts brain activations when participants received touch by sandpaper. (D) shows that the contrast rough relative to smooth and smooth relative to rough, respectively, failed to show significant activations (at $p < 0.05$, FDR corrected). Areas of significant fMRI signal change are shown as color overlays on the T1-MNI reference brain. Both (A), (B), and (C) demonstrate involvement of left SI and SII.

Figure 3: Statistical maps showing brain activation while participants assessed ambiguous social scenarios with respect to social coordination (SCI). Areas of significant fMRI signal change are shown as color overlays on the T1-MNI reference brain. A: Judging the SCI when primed with rough relative to no touch demonstrated activation in SI (and hippocampus) and IFG. B: Judging the SCI when primed with rough relative to smooth touch revealed similar areas in SI and IFG.

Figure 4: Statistical maps showing brain activation in SI and SII while assessing ambiguous social scenarios for the contrast rough relative to no priming (A) and rough relative to smooth priming (B), masked with brain responses when receiving real touch. A: Activity in left SI could significantly predict reduced social coordination scores. SII failed to show significant activation. B: Activity in left SI again predicted the reduced social coordination assessments. SII displayed no significant relationships.

Figure 5: Statistical maps displaying brain activation when assessing scenarios with respect to social coordination (SCI) relative to relationship familiarity (RFI), masked with brain responses when receiving real touch. A: When primed with rough touch SI and SII showed activation. B: When primed with smooth touch no brain areas showed activation (at $p < 0.05$, FDR corrected). C: Overlap of brain activation in SI between rough priming for SCI relative to RFI (green) and rough relative to smooth priming for SCI (red). Voxels involved in both contrasts are marked in yellow.

Table 1. Results of random effects analysis for social coordination judgments ($p < 0.05$, FDR corrected, L=left hemisphere, R= right hemisphere).

contrast	brain region	peak MNI location (x, y, z)	peak z-value	number of voxels
rough priming > smooth priming	L SI	-28 -42 58	3.88	373
	premotor cortex (BA6)	-4 -16 56	3.73	287
	R inferior frontal gyrus (BA45)	54 28 2	4.07	122
	L hippocampus / amygdala	-16 0 -10	3.56	70
smooth priming > rough priming	-	-	-	-
rough priming > no priming	L SI	-32 -30 48	4.25	4549
	L SII	-60 -20 27	3.16	
	R SI	18 -41 65	4.00	
	R / L premotor cortex (BA6)	20 -20 50	4.49	
	L inferior parietal cortex (IPC)	-58 -36 24	3.07	
	R inferior frontal gyrus (BA45)	52 28 -4	3.32	76
	L inferior frontal gyrus (BA45)	-44 30 -6	3.53	275
	L hippocampus / amygdala	-18 -8 -14	3.80	318
	R hippocampus / amygdala	40 -6 -20	3.56	168
	R inferior parietal cortex (IPC)	66 -36 20	4.19	120
smooth priming > no priming	-	-	-	-

Table 2. Results of random effects analysis for social coordination judgments relative to familiarity relationship judgments ($p < 0.05$, FDR corrected, SCI = social coordination index, RFI = relationship familiarity index).

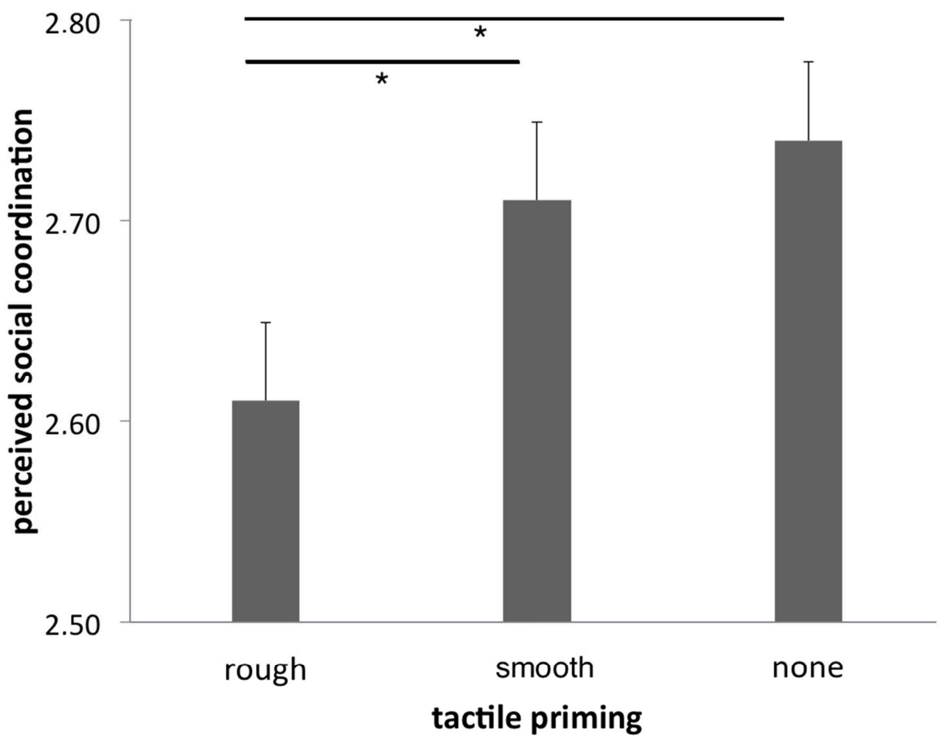
contrast	brain region	peak MNI location (x, y, z)	peak z-value	number of voxels
rough priming SCI > rough priming RFI	L SI / premotor cortex (BA6) R inferior frontal gyrus (BA45) L inferior frontal gyrus (BA44) L IPC R IPC	-14 -44 70 54 24 0 -58 10 8 -54 -38 23 62 -42 23	3.88 3.56 3.32 3.79 3.56	658 248 175 187 180
rough priming RFI > rough priming SCI	-	-	-	-
smooth priming SCI > smooth priming RFI	-	-	-	-
smooth priming RFI > smooth priming SCI	-	-	-	-

Table 3. Results of random effects analysis, masked with brain responses during real touch ($p < 0.05$, FDR corrected).

	contrast	brain region	peak MNI location (x, y, z)	peak z-value	number of voxels
SCI	rough priming > smooth priming	L SI L SII	-30 -40 58 -62 -18 22	3.78 2.46	738 22
	smooth priming > rough priming	-	-	-	-
	rough priming > no priming	L SI L SII	-32 -32 62 -60 -18 22	4.10 3.05	1196 418
	smooth priming > no priming	-	-	-	-
RFI	rough priming > smooth priming	-	-	-	-
	smooth priming > rough priming		-	-	-
	rough priming > no priming	-	-	-	-
	smooth priming > no priming	-	-	-	-

Table 4. Results of random effects analysis for social coordination judgments relative to familiarity relationship judgments, masked with brain responses during real touch ($p < 0.05$, FDR corrected).

contrast	brain region	peak MNI location (x, y, z)	peak z-value	number of voxels
rough priming SCI > rough priming RFI	L SI L SII	-36 -36 64 -50 -30 16	3.65 3.15	641 161
rough priming RFI > rough priming SCI	-	-	-	-
smooth priming SCI > smooth priming RFI	-	-	-	-
smooth priming RFI > smooth priming SCI	-	-	-	-



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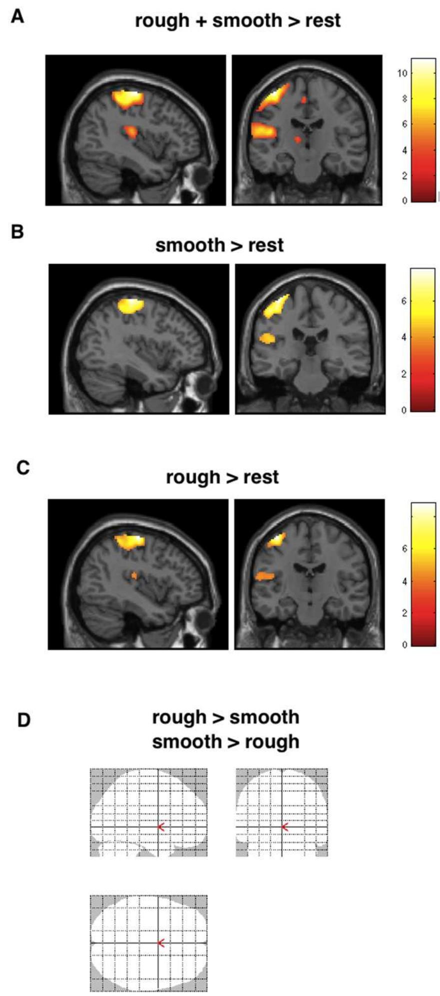

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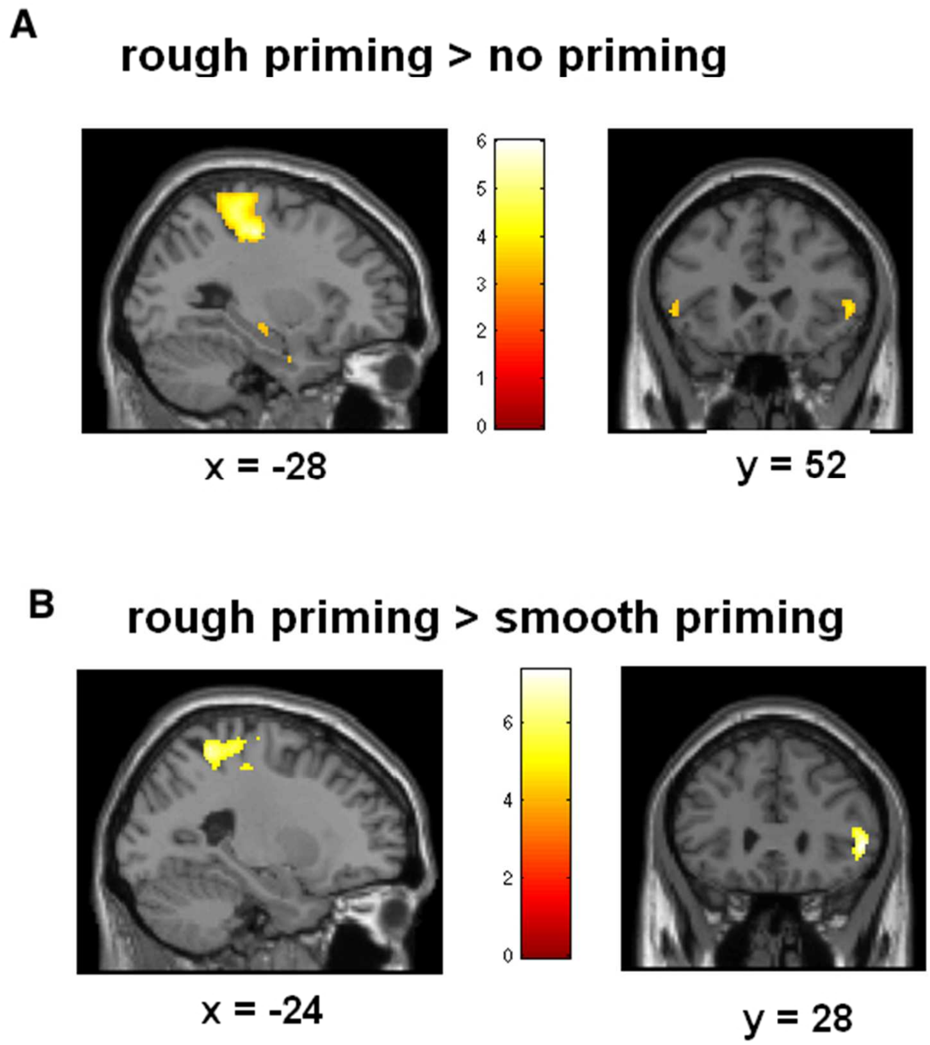

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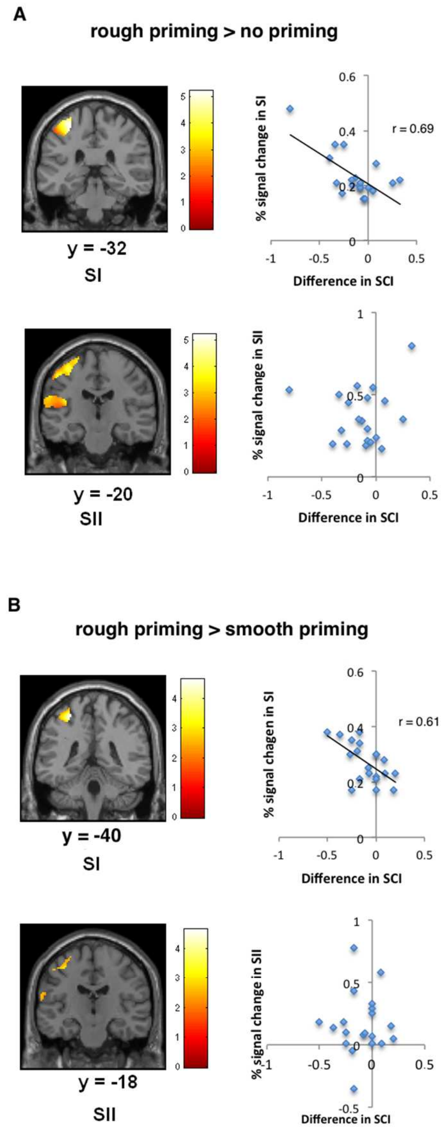

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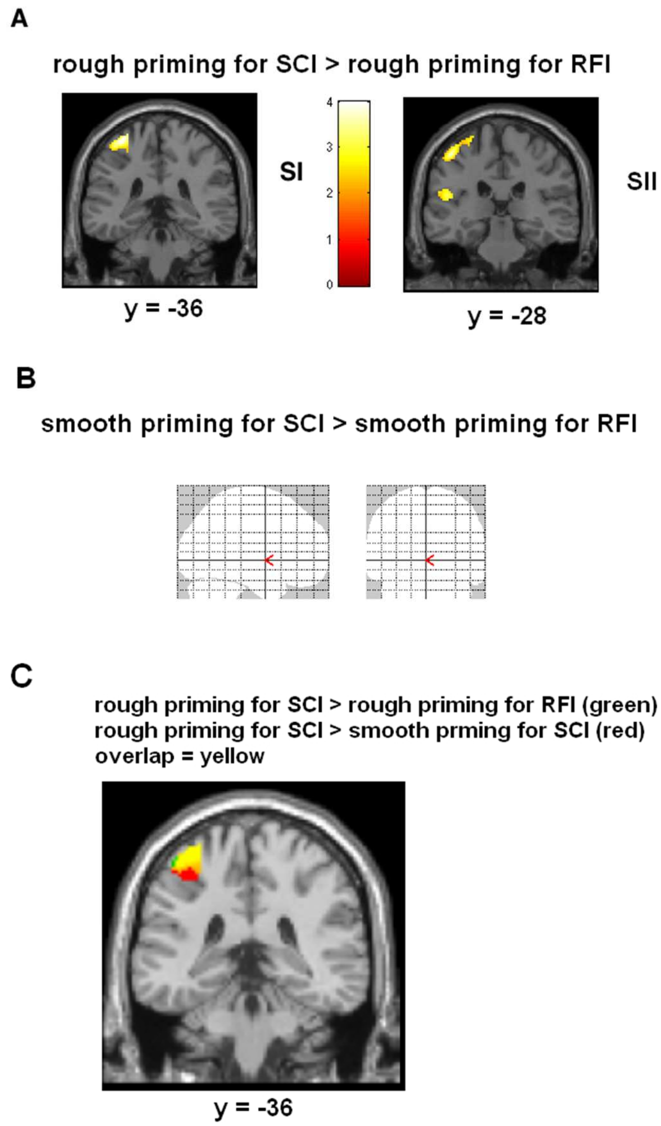

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