Constructing meaning: Material products of a creative activity engage the social brain

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Abstract

Symbolic artifacts present a challenge to theories of neurocognitive processing due to their dual nature: they are both physical objects and vehicles of social meanings. While their physical properties can be read of the surface structure, the meaning of symbolic artifacts depends on their embeddedness in cultural practices. In this study, participants built models of LEGO bricks to illustrate their understanding of abstract concepts. Subsequently, they were scanned with fMRI while presented to photographs of their own and others' models. When participants attended to the meaning of the models, we observed activations associated with social cognition and semantics. In contrast, when attending to the physical properties, we observed activations related to object recognition and manipulation. Furthermore, when contrasting own and others' models, we found activations in areas associated with autobiographical memory and agency. Our findings support a view of symbolic artifacts as neuro-cognitive trails of human social interactions.

Keywords: symbolic artifacts; mPFC; TPJ; IFG; social cognition; cultural practice

Introduction

A central human characteristic is our profound engagement with material objects and technologies. Like no other species we actively shape, explore and exploit our material surroundings to construct cultural and cognitive niches (Clark, 2006; Laland, Odling-Smee, & Feldman, 2000). While our material inventions include sophisticated tools for instrumental and pragmatic engagement of the environment, another broad class, *symbolic artifacts*, does its work by virtue of *meaning*. Objects such as national flags, religious symbols, artworks, road signs, pictorial representations etc. are imbued with social significance as they are developed, negotiated and engaged in a variety of cultural practices. More than mere physical objects, we thus experience them as vehicles of social meaning: a red traffic light does not present any physical impediment to movement, and yet it (most often) stops us. This raises fundamental questions concerning the neuro-cognitive status of symbolic artifacts: which patterns of functional activations are related to the perception of social meaning in objects?

Previous brain-imaging studies have focused on the distinction between social versus non-social, or animate versus inanimate stimuli, and report dissociable networks of brain areas in reaction to these categories (Caramazza & Shelton, 1998; Gobbini et al., 2011; Naselaris, Stansbury, & Gallant, 2012). For instance the dorso-medial prefrontal cortex has been suggested to activate only when participants make judgments about other people and not objects (Mitchell, Heatherton, & Macrae, 2002; Mitchell, Neil Macrae, & Banaji, 2005). The assumption behind these studies is that stimuli come in ontologically pre-defined categories - for instance all objects are considered non-social, while people are social - and patterns of functional brain activations are interpreted according to these specific categories.

However, as previously argued, symbolic artifacts constitute a challenge to this literature due to their double nature: they are simultaneously physical entities and vehicles of non-tangible cultural meanings (Clark, 2006; Hutchins, 2005), and this implies that they might give rise to distinctive patterns of functional brain activations according to how they are approached. Additionally, while their physical nature is easily appreciable, their social meaning is often not fully transparent to the casual newcomer, but critically depends on participation in cultural practices and trajectories of actual use in social interactions (Hutchins, 2008; Tylén, Fusaroli, Bundgaard, & Østergaard, 2013).

The complex social nature of symbolic artifacts motivates a different set of hypotheses concerning their neurocognitive bases: Functional brain activation will be modulated by i) the interpretive attitude by which we approach the objects (as physical entities or as meaningful symbols), and ii) by our familiarity with the socio-cultural practices constituting the meaning of the objects. In other words, if socially symbolic dimensions are contextually actualized, we expect objects to evoke activity in the brain areas related to social cognition and semantics such as mPFC, TPJ and IFG (Tylén, Allen, Hunter, & Roepstorff, 2012; Tylén, Wallentin, & Roepstorff, 2009). Furthermore, we expect this activity to be modulated by participation in the social history of the object (Mano et al., 2011). In contrast, if the bare physical properties of the same artifacts are profiled, we expect them to activate areas related to object recognition and manipulation, such as ventral temporal and motor areas (Bar et al., 2001; Binkofski et al., 1999). To investigate these predictions we designed a two-part study in which participants were instructed to individually and collectively build their understanding of abstract concepts using LEGO blocks. On the following day participants were shown pictures of LEGO models built by themselves or others while they were scanned with fMRI. In the scanner they were given assignments that primed them to perceive the LEGO constructs either as bare physical structures or as vehicles of socially constituted meaning.

Materials and Methods

Participants

30 participants (15 f, mean age 23.6, sd 2.6) were recruited among students of Aarhus University and received monetary compensation for their participation. All participants were right-handed, native speakers of Danish, with no history of neurological or mental problems. Informed consent was obtained in a manner approved by the local research ethical committee.

Design and Procedure

The experiment was carried out as a two-part study over two days. On the first day, participants were engaged in individual and collective LEGO construction activities. On the following day participants went through an fMRI brain scan in which they were subjected to photographic stimuli depicting the products of the preceding day's individual and collective LEGO constructions.

The LEGO construction activity The first day LEGO construction activity was organized as a two-condition within-group contrast: collective vs. individual. Participants were organized in mixed-gender groups of four to six. Group members did not know each other in advance. Participants of each group were organized around a table facing each other. Two simpler practice trials served to familiarize them with each other and the LEGO materials. After that, groups underwent an interleaved series of six individual and six collective LEGO construction tasks of each five minutes. In the construction tasks, participants were instructed to use LEGO blocks to illustrate their understanding of six abstract concepts: 'responsibility', 'collaboration', 'knowledge', 'justice', 'safety' and 'tolerance'. The concepts were selected to be challenging to build, yet sufficiently common in public discourse that participants would have an opinion about them. The LEGO materials were in all cases a LEGO Serious Play Starter Kit consisting of 214 mixed pieces (standards bricks in varying shapes and colors, wheels, LEGO people, etc.). In order to constrain variability of complexity and size of the models, participants were instructed to build their models within the limits of an A5 (5.8 x 8.3 inch) piece of cardboard.

In individual trials, participants sat quietly and constructed their own models. In collective trials participants freely interacted to construct joint models. After each trial, participants were asked to briefly explain their model. The experiment was divided in two 3-concepts sessions separated by a 20 min. break. Two video cameras consecutively recorded the construction activities and after each construction trial the resulting LEGO models were photographically documented with a Canon digital camera.

The fMRI study On the following day, participants came back to the lab individually for an fMRI brain scanning session. In the scanner, they were presented with photographic stimuli depicting resulting models from the LEGO construction activities. These belonged to four conditions making up a 2-by-2 factorial design with the factors collective/individual and own/other: 1) models that the participant made with her group, 2) models that the participant made individually, 3) models made by another group, and 4) models made by another individual (from another group). All corresponding LEGO models were presented twice from two different perspectives in a randomized order, each time accompanied by one of two rating tasks: a 'meaning property' and a 'physical property' task. The tasks were intended to modulate participants' attitude to the stimuli, inspecting the models for either their meaning potentials, which critically depended on their complex social histories, or their bare physical appearance that did not - to the same extend – depend on memories of their creation.

In the meaning related task, participants would first see a prompt (1.5 sec) indicating that they would be subjected to a meaning related task. Thereafter they would see one of the six target concepts ('responsibility', 'safety' etc.) written on the screen (2 sec) followed by an image of a LEGO models depicting this target concept (shown for 3 sec). Then they would be prompted to rate the model on a 6-point scale from "not well" to "very well" in response to the question "How well do you think this model represents the concept X?"

In the physical property related task, participants would first be prompted that they would be subjected to a physical property task (1.5 sec). Then they would be presented with an image of one of the LEGO models from one of the four conditions (3 sec). After this they were prompted to rate the model on a 6 point scale from "fragile" to "robust" in response to the question "How fragile/robust do you find this model?".

In both types of rating tasks, participants performed their rating by moving a cursor to the desired place on the rating scale by tapping a response box button with the right hand index finger and then submit the decision using the right-hand middle finger. Participants were instructed to complete their rating within 5 sec after which a time-out would occur and the procedure would proceed to the next trial.

fMRI acquisition parameters and analysis

We used a 3T Siemens TIM Trio MRI system with a 12 channel head coil to acquire the T2* weighted gradient echo, echo-planar images (EPI) with Blood Oxygenation Level-Dependent (BOLD) contrast using the following parameters: echo time (TE): 30 ms, repetition time (TR): 3000 ms, and a flip angle of 90°. Whole-brain images were obtained over fifty-six sequential, interleaved 2.5 mm axial slices with a 3 x 3 mm resolution and a field of view of 192 x 192 mm.

All fMRI data analyses were conducted using SPM8 (Statistical Parametric Mapping, Wellcome Department of Imaging Neuroscience, London) implemented in MATLAB using default settings unless otherwise specified. Images were spatially realigned, normalized to the MNI template and smoothed with an isotropic 8mm FWHM Gaussian kernel. Statistical analysis was conducted following a two-level general linear model approach (Penny & Holmes, 2007). On the first-level, single participant task-related BOLD responses were modeled for each subject by convolving condition onsets and durations with the standard hemodynamic response function and effects for each condition were estimated using a general linear model approach. The main contrast concerned perception of the LEGO models in the meaning-related versus the physical property-related task. Then, for the meaning related task, main and interaction effects of the four conditions were modeled. Besides the analysis included standard regressors for the six SPM8 motion parameters and a high-pass filter set to 128 s cut off. Contrast images from the first-level analysis went into a second-level RFX group analysis using the one-sample *t*-tests in SPM8. The significance threshold for all main effects was set to $p < .05$, FDR corrected for multiple comparisons, while selected interaction effects were explored also at uncorrected thresholds. Functional images were overlaid with the standard SPM8 single subject high resolution T1 image.

Results

Contrasting the 'meaning' > 'physical property' related task yielded patterns of activation in a bilateral network of brain areas comprising mainly the dorso-medial PFC, TPJ, and inferior frontal gyrus (see table 1A for peak voxels and stats and fig. 1A). The opposite contrast, 'physical property' > 'meaning' related task, yielded activations in the right precentral gyrus, the fusiform gyrus bilaterally, and the primary occipital cortex bilaterally (table 1B and fig. 1B). The four factorial conditions were tested separately for the two tasks.

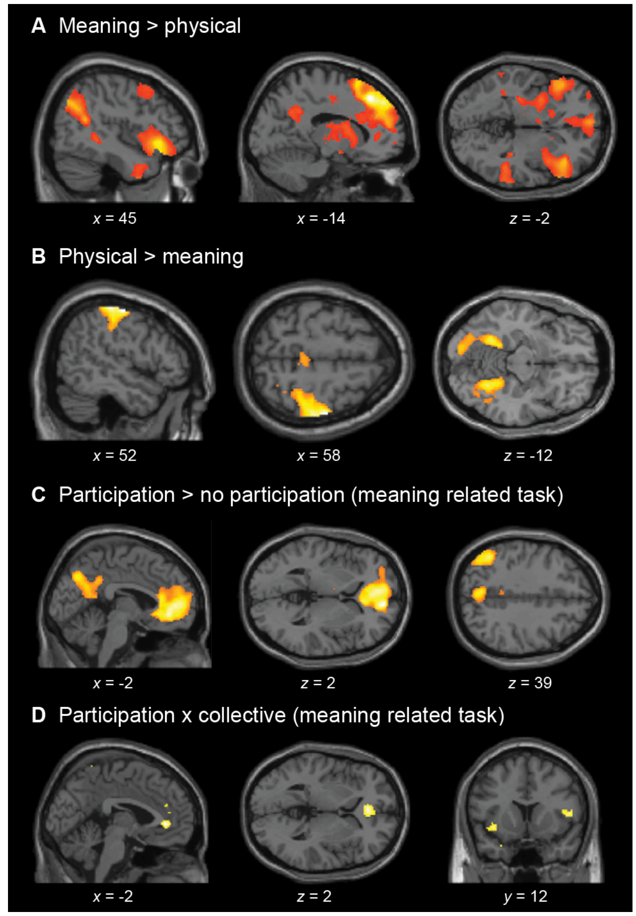

Figure 1: graphical depiction of fMRI activation sites

Table 1: coordinates and anatomical regions

Anatomical site	Left hemisphere Z-score	MNI coordinates x	y	z	Right hemisphere Z-score	MNI coordinates x	y	z
A Meaning > Physical								
Dorsal mPFC	8.04	-14	48	44	7.47	10	48	42
TPJ	7.58	-46	-60	28	6.18	50	-68	36
IFG	5.95	-52	28	-8	7.52	52	30	-12
Postcentral gyrus	6.05	-34	-24	48	-	-	-	-
Temporal pole	-	-	-	-	4.32	42	5	-44
B Physical > Meaning								
Precentral gyrus	-	-	-	-	7.94	52	-14	58
Fusiform gyrus	6.39	-24	-54	-14	6.67	28	-56	-12
Paracentral lobule	-	-	-	-	4.40	2	-32	56
Primary occipital	4.91	-14	-88	-10	3.79	18	-86	-8
C Participation > no participation (meaning related task)								
mPFC	-	-	-	-	7.69	10	56	4
Anterior cingulate	6.99	4	32	10	-	-	-	-
TPJ	6.33	-44	-58	40	-	-	-	-
Precuneus	6.12	-8	-56	18	-	-	-	-
D Participation x collective (meaning related task), $p < .001$, uncorrected								
Anterior cingulate	5.53	-2	38	2	-	-	-	-
IFG	-	-	-	-	4.73	50	12	8
Insula	4.54	-35	12	-8	-	-	-	-

For the meaning related task, the contrast 'participation' > 'no participation' activated the right medial prefrontal and anterior cingulate cortex, left TPJ and precuneus (see table

1C and fig. 1C). The opposite contrast, 'no participation > participation' and both main effects of collective/individual did not yield above threshold results, however the interaction 'participation' > 'no participation' * 'collective' > 'individual' activated a network comprising left anterior cingulate cortex, right inferior frontal gyrus and L insula (see table 1D and fig. 1D). No other contrasts were found to be significant.

Discussion

We found differential patterns of brain activation when participants were primed to perceive LEGO models as physical constructs (rating their fragility) and when they approached them as vehicles of socially constituted meaning. Rating the relative fragility of a model calls attention to the physical surface properties of the structure and might imply imagining to haptically manipulate it in order to make judgments. This activity was found to activate the fusiform gyrus bilaterally and areas of right pre-central gyrus were activated. Both sites have previously been found related to perception of physical objects (Shmuelof & Zohary, 2005). While the fusiform gyrus is mostly associated with object recognition and categorization (Bar et al., 2001; Chao, Haxby, & Martin, 1999; Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999; Grill-Spector, 2003), motor areas seem particularly sensitive to mental object manipulation (Vanrie, Beatse, Wagemans, Sunaert, & Van Hecke, 2002).

In contrast, rating the expressive qualities of the models requires participants to pay special attention to the meaning potentials of the models, which might imply 1) recalling the particular social practices in which these meanings evolved, and 2) reading the models as communicative symbols (not unlike gestures, figurative signs or even words). This task was found to activate a bilateral network of areas comprising dorso-medial prefrontal cortex, TPJ and IFG was activated. The mPFC and TPJ are consistently found in studies of social cognition and interaction, and generally associated with mentalizing, agency, and ascription of intentionality (Amodio & Frith, 2006; Frith & Frith, 2006; Iacoboni et al., 2004; Van Overwalle, 2009). Interestingly, previous studies have claimed this area to only activate when participants made judgments about other people and not objects (Mitchell et al., 2002; Mitchell et al., 2005). We suggest that the activation of mPFC and TPJ reflects how meaning related rating task actualizes the particular social history constituting the meaning dimension of the stimulus LEGO models (Mano et al., 2011; Schaefer & Rotte, 2010). We also found activations of the IFG bilaterally. IFG, particularly in the left hemisphere, is traditionally considered a "language area" and consistently shows up in studies on verbal semantics (A. J. Newman, Pancheva, Ozawa, Neville, & Ullman, 2001; S. D. Newman, Just, Keller, Roth, & Carpenter, 2003; Rodd, Davis, & Johnsrude, 2005). However, recent studies suggest generalizing the function of these areas to semantic aspects of other modalities of communication and expressivity as well. For instance, the IFG has been found in studies of hand gestures (Dick, Goldin-Meadow, Hasson, Skipper, & Small, 2009; Xu, Gannon, Emmorey, Smith, & Braun, 2009), facial expressions (Jabbi & Keysers, 2008), music (Vuust et al., 2005), as well as studies on symbolic objects (Tylén et al., 2009). It is often noticed that in case of non-verbal (or complex verbal) stimuli, bilateral activation patterns are more prevalent, suggesting higher processing demands due to differential levels of complexity, conventionalization or expertise (Tylén et al., 2009; Vuust et al., 2005; Yang, Edens, Simpson, & Krawczyk, 2009). We suggest that the activation of IFG in this experiment is related to the way participants explore the LEGO models as communicative signs not unlike verbal or gestural signals (Tylén, Bjørndahl, & Weed, 2011).

Within the meaning-related condition, we found a strong main effect of participation - that is - watching models that the participant had constructed herself individually or with her group in contrast to models built by other individuals/groups. Making assessments of your own (known), collective and individual models could be expected to depend more on episodic memory traces: the participant's judgments of the meaning related properties of the models rely in part on personal recollections of the preceding building activities and discussions and perhaps to a lesser extent on semantic memory and processing. Accordingly, this contrast yielded activation in social cognition areas such as mPFC, anterior cingulate and left TPJ. This seems to replicate findings from previous studies investigating the contrast between self-generated and other generated texts (Mano et al., 2011). Interestingly, we do not find the meaning-related pattern of IFG activation in this contrast, which suggests that IFG is involved in more general explorations of meaning across own and others' models. However, we observed additional activations of left precuneus, an area consistently found in studies of autobiographical memory and experience of agency (Cavanna, 2006; Maddock, Garrett, & Buonocore, 2001).

Lastly, we found an interaction effect between our main factors: When participants made assessments of their own models from the collective condition (in contrast to other's/individual), we found activation in the anterior cingulate, the right IFG and the left insula. The insula is interesting in this respect as it is often associated with social emotions (Phan, Wager, Taylor, & Liberzon, 2002) and empathy (Singer, 2006; Singer & Lamm, 2009). Furthermore, it has been suggested that the insula forms a network with the anterior cingulate cortex sensitive to the saliency of stimuli and events (Menon & Uddin, 2010). It seems likely that the more arousing character of collective building activities (in contrast to individual building activities) make these models more salient to the participant and thus evoke stronger insula and anterior cingulate activations.

Conclusions

In this study we investigated the neurocognitive status of symbolic artifacts. Together our findings support the idea that symbolic artifacts are simultaneously physical objects and vehicles for non-tangible social meanings. Very different neurocognitive processes are involved in attending to physical features and social meanings, and in the latter case they are modulated by a history of social engagement of the object. Symbolic artifacts can thus be conceived as material and neuro-cognitive trails of social interactions and cultural meanings.

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