Decoding social knowledge in the human brain

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Motivation

How does the brain represent conceptual meaning about the attitudes, beliefs, or emotions of other people?

We have extensive evidence that we can use BOLD activity to classify conceptual knowledge using a variety of **concrete** concepts (e.g. *animals* or *tools*; JV Haxby 2012 Neuroimage).

Only recently there has been a similar interest in studying the brain representations of **abstract** concepts (M Ghio et al. 2016 Neuroimage; Y Wang et al. 2017 PNAS).

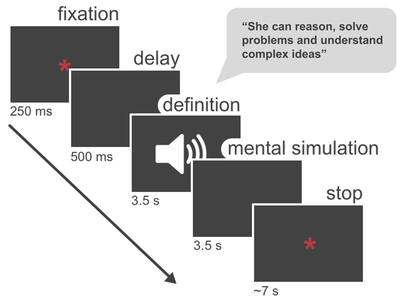
Abstract conceptual knowledge about others likely involves a range of underlying dimensions, yet it is unknown whether (and how) the brain maps different aspects of social information. We investigated the brain representations of social knowledge associated with two fundamental processes in social cognition: **affect** and **likableness** (NH Anderson 1968 J Pers Soc Psychol).

This fMRI study investigated the representation of abstract social concepts in the human brain using multivariate pattern analysis (MVPA).

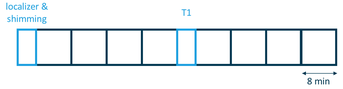
Experiment

We asked participants (n = 30; mean age 24.07 ± 3.67 years; 18 females) to rate on a scale from 0 to 100 how *likable* and *affective* was each social concept before and after the scanning session.

During the fMRI session participants listened to short definitions of social concepts and then **mentally simulated** another individual behaving the way described in the definition:



A scanning session was composed of 8 functional runs and a structural run halfway through the session.



Each functional run contained 36 trials (one trial per social concept; 9 concepts for each concept class). A trial consisted on the auditory presentation of the definition of the social concept for 3.5 seconds followed by another short period of 3.5 seconds to **mentally simulate the referred behavior**.

Decoding the brain representation of social concepts

1 The intraclass correlation coefficient shows a fair test-retest repeatability for the ratings of *affect* and excellent for the ratings of *likableness*.

ID	Concept	Pre	Post	Dimension
sub-001	Boring	20	10	likableness
sub-001	Good-natured	65	70	likableness
sub-001	Thankful	81	72	likableness
sub-001	Cheerful	95	80	likableness
...	...	...	...	
sub-030	Resentful	50	70	affect
sub-030	Sensible	100	95	affect
sub-030	Honest	50	50	affect
sub-030	Lazy	10	0	affect

ICC_{affect} = 0'47 [0,36-0,60]
$ICC_{likableness}$ = 0'93 [0,89-0,96]

2 Ratings of affect *(red)* of concepts related to affective states were significantly higher than those related to non-affective mental states ($t_{(29)}$ = 8.026, p < 0.001, d = 1.465) and ratings of likableness *(grey)* of socially desirable concepts were significantly higher than those of socially undesirable concepts ($t_{(29)}$ = 30.382, p < 0.001, d = 5.547; see **Fig. 1**)

3 Subjective ratings suggest that the *likableness* of others' behavior can weigh more heavily on how we represent social knowledge than *affect*.

4 A set of repeated-measures ANOVAs with one factor (ROI) showed significant differences in decoding accuracy among ROIs for each classification problem.

		Sum of Squares	df	Mean Square	F	p	ω²
Partition CV	Affect	0.086	8	0.011	19.505	< .001	0.244
	Likableness	0.240	8	0.030	30.888	< .001	0.267
Item CV	Affect	0.040	8	0.005	8.195	< .001	0.240
	Likableness	0.176	8	0.038	23.531	< .001	0.218

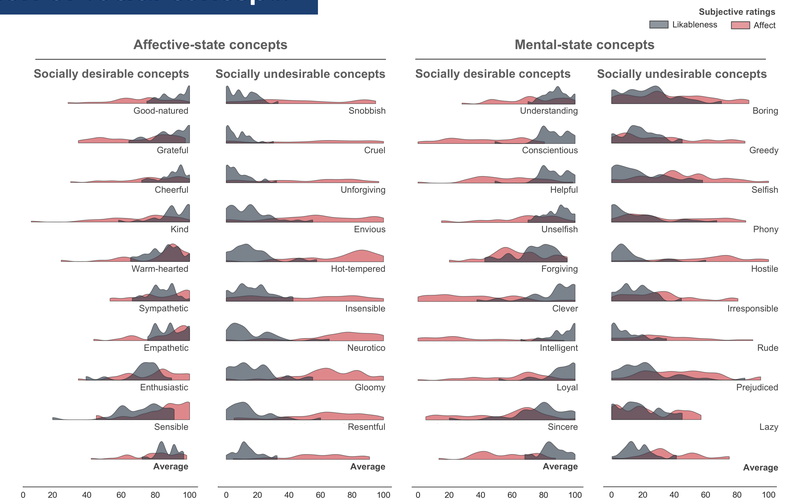


Figure 1. Distribution of ratings of social concepts. Participants read each concept definition and rated whether the described behavior involved the emotions of oneself or others (affect; *red*) as well as whether such behavior was socially desirable (likableness; *grey*) on a scale from 0 (very nonaffective; very unlikable) to 100 (very affective; very likable).

5 A repeated-measures ANOVA with two factors: ROI and dimension of social information (i.e. affect vs. likableness) showed a significant main effect of dimension for both the cross-validation procedures (see **Fig. 2**).

		Sum of Squares	df	Mean Square	F	p	ω²
Partition CV	ROI	0.289	8	0.036	39.395	< .001	0.314
	Dimension	0.034	1	0.034	7.801	0.009	0.054
	ROI * Dimension	0.037	8	0.005	7.640	< .001	0.056
Item CV	ROI	0.171	8	0.033	27.657	< .001	0.334
	Dimension	0.033	1	0.033	2.938	0.097	0.043
	ROI * Dimension	0.045	8	0.009	7.281	< .001	0.105

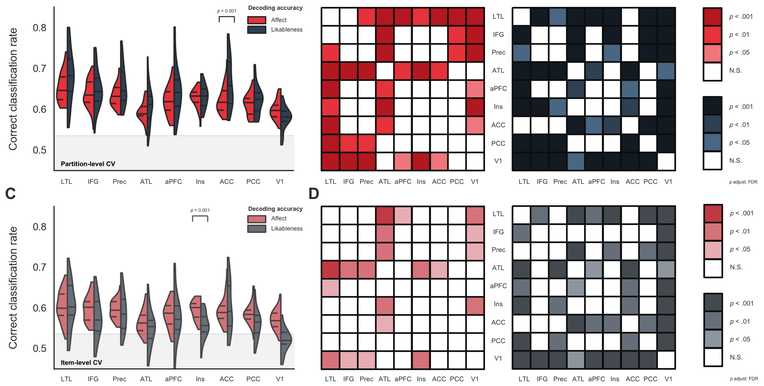


Figure 2. Decoding accuracies of social concepts across the brain. Classification accuracy of both the affect and likableness of social knowledge using partition-level **(A)** as well as item-level **(C)** cross-validation procedures. Panels **(B)** and **(D)** show *post hoc* paired *t*-tests of separate repeated-measures ANOVAs with one factor (ROI) for affect *(red)* and likableness *(grey)* for both CV procedures.

6 *Post hoc* paired *t*-tests showed that the interaction effect was driven by the ACC ($t_{(29)}$ = 4.461, p = 0.001, d = 0.814), which showed a preference for the likableness dimension when using the partition-level CV. On the other hand, the interaction effect was driven by the Ins ($t_{(29)}$ = -4.623, p = 0.001, d = 0.844), which showed a preference for the affect dimension instead when using the item-level CV.

7 Finally, we compared whether social knowledge was differentially represented in ROIs selected as canonical semantic regions (i.e. the LTL, IFG, and Prec) to ROIs selected as social information processing regions (i.e. the Ins, ACC, and PCC; see **Fig. 3**). Paired *t*-tests showed that mean classification accuracy was significantly higher in semantic ROIs for both affect ($t_{(29)}$ = 5.590, p < .001, d = 1.021) and likableness ($t_{(29)}$ = 5.113, p < .001, d = 0.933) using partition-level cross-validation. Similarly, mean decoding accuracy was higher in semantic ROIs for both affect ($t_{(29)}$ = 2.519, p = 0.018, d = 0.460) and likableness ($t_{(29)}$ = 4.133, p < .001, d = 0.755) using item-level cross-validation.

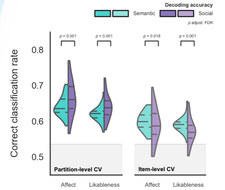


Figure 3. Decoding accuracy of social concepts in semantic vs. social ROIs. Classification accuracy in semantic ROIs was significantly higher than in social ROIs using both partition- and item-level cross-validation procedures. The shaded area indicates the mean empirically estimated chance level (mean = 0.53).

Statistical analysis

fMRI data was preprocessed as follows: (i) removal of non-brain tissue using FSL's BET; (ii) volume realignment using MCFLIRT; (iii) gaussian kernel (FWHM = 3mm) for spatial smoothing; (iv) ICA-based automatic removal of motion artefacts; (v) temporal filtering (high-pass; cutoff = 60s); (vi) coalignment of each session to a reference volume (1st session).

After stacking, detrending, and z-scoring each ROI's BOLD data we used an **SVM-based linear classifier** to decode the brain representation of social concepts regarding: (i) their *likableness* (high vs. low) and (ii) their *affect* (high vs. low). We used a PCA-based feature selection within each ROI and leave-one-out cross-validation (300 permutations).

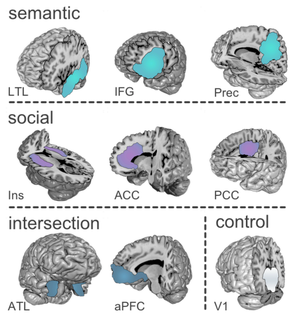
For the cross-validation (CV) procedure, we first used **partitions** of the stacked BOLD data as left-out samples to test the classifier. As a robustness check, we also performed another CV using entire **items** (i.e. concepts) as left-out sample for testing to better ensure out-of-sample generalization.

To obtain an empirical estimate of chance level performance, we trained a classifier on examples with randomly shuffled labels and then tested on the examples labelled appropriately. Statistical significance of above-chance decoding accuracy was then tested using paired t-tests corrected for the number of ROIs.

Statistical significance of decoding performance at the group level was assessed with two repeated-measures ANOVAs with one factor (ROI) to analyze differences between ROIs. Then, to further explore whether our ROIs showed a bias towards decoding more the affect or likableness of social knowledge, we performed a repeated-measures ANOVA with two factors: ROI and dimension of social information (i.e. affect vs. likableness). Finally, we used paired t-tests to compare the average decoding accuracy in semantic ROIs compared with social ROIs

We focused on a set of **regions of interest** (ROIs) based on previous studies on semantic (JR Binder et al. 2009 Cereb Cortex) and social information processing (D Alcalá-López et al. 2017 Cereb Cortex):

+ 3 semantic regions (lateral temporal lobe, LTL; inferior frontal gyrus, IFG; and precuneus, Prec)
+ 3 social regions (insula, Ins; anterior cingulate cortex, ACC; posterior cingulate cortex, PCC)
+ 2 semantic & social regions (anterior temporal lobe, ATL; anterior prefrontal cortex, aPFC)
+ 1 control region (primary visual cortex, V1)



Take-home messages

Putative semantic regions, such as the lateral temporal lobe, inferior frontal gyrus, and precuneus, outperformed on average canonical social ROIs including the insula, anterior cingulate, and anterior prefrontal cortex.

The lateral temporal lobe contains the most information about the affect and likableness of social concepts. However, we also found evidence that the insula shows a bias towards the affect, and the anterior cingulate towards the likableness, of social concepts.

Our results do not support a modular view of the representation of social concepts and are rather consistent with the view that socially relevant knowledge relies on a widely distributed brain network.

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