Two domains of human higher cognition

distinct brain networks underlie social and mechanical reasoning

CWRU
Department of Cognitive Science
Transdisciplinary approaches to the mind

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Introduction

Folk psychology (i.e. 'common sense') has long held a distinction between social reasoning (e.g. the ability to discern the beliefs, intentions and emotions of others) and mechanical reasoning (e.g. the ability to understand physical principles and predict the operation of mechanical objects). In contrast, psychologists have often speculated that these domains rely on the same underlying processes. To shed further light on this issue, we set out to examine the degree to which these two domains of human higher reasoning recruit distinct or overlapping brain areas.
We used a two factor crossed design to examine the brain areas recruited during social and mechanical reasoning, using problems presented in two different modalities: text and video. This allowed us to examine the cognitive domains independent of stimulus modality. Note that the perceptual demands for the conditions were very similar or identical within each modality.

Experimental Design and Analysis

Subjects and procedure
Participants (N=9) were scanned using a 4T Bruker-Siemens MR scanner. Each participant underwent T1 and T2w structural scans, followed by 5 BOLD runs of 300 volumes (3.8mm cubic voxels using 38 slices, TR=2s, flip angle of 90, TE=20).
Each BOLD run consisted of 4 presentations of each of the 4 conditions, and 4 rest periods, for a total of 20 blocks per BOLD run. BOLD runs lasted 10 minutes.
Each block lasted 27 seconds. In the non-rest conditions this consisted of 20 seconds for presentation of a video or on-screen text, followed by 7 seconds for reading and responding to the related yes/no question. Responses were made using a key pad. The rest condition consisted of 27 seconds of passive viewing of a fixation cross. Order of conditions and rest periods within each BOLD run was randomized for each subject. Brief fixation periods of variable duration (1, 3 or 5s) separated each block period.
A practice block was given during structural image acquisition and consisted of 2 examples of each of the 4 conditions and 2 rest periods.

Analysis
After calculation of parameters for realignment within each BOLD run, and for coregistration of each BOLD run with the atlas aligned T1 structural image, BOLD stacks were resampled directly from the raw data into a 3mm cubic voxel atlas space. Each BOLD stack was then spatially smoothed with a Gaussian 3D filter with FWHM of 2 voxels (6mm).
Rainbow plots (see top middle panel) for each BOLD run were derived from visual cortex. These served as a data quality check and to ensure event files were correct.
Data for each subject was entered into a general linear model in which baseline and linear trend were estimated alongside a single a single uniform assumed response associated with each condition.

Conditions

The ***physics movie condition*** consisted of clips taken, with permission, from the Video Encyclopedia of Physics. These short videos allow the participant to both view and hear a description of a physical event or phenomena. Correct response to the question requires the participant to understand the mechanical processes that the video portrays and then apply intuitive knowledge of physics to predict the physical outcome of the situation.

The ***social movie condition*** comprised short scenes in which two actors engaged in an emotionally laden communication, which typically involved a degree of misunderstanding. Questions focused on the feelings, beliefs, desires, and intentions of the individuals in the video. Understanding of the situations and correct response to the questions requires the participant to detect subtle differences in tone and body language, as well as the application of basic social knowledge and Theory of Mind (knowledge that other's beliefs, desires, and intentions differ from one's own).

The ***physics story condition*** texts were adapted from public domain science puzzles. The texts consist of the text description of physical events or phenomena. The participant must understand the mechanical processes involved and utilize basic knowledge of physical principles to correctly respond to a question about the physical outcome of the situation.

The ***social story condition*** texts were adapted from Saxe & Powell, 2006 to add greater emotional content to the existing false belief content. The texts depict a situation that requires understanding of the feelings, beliefs, desires, and intentions of one or more story characters in a plausible social situation. Understanding of the situations and correct response to the questions requires the participant to think past the information contained in the text and infer the effects e.g. of a false belief or a frustrated desire.

The ***rest condition*** involves the passive viewing of a red fixation dot.

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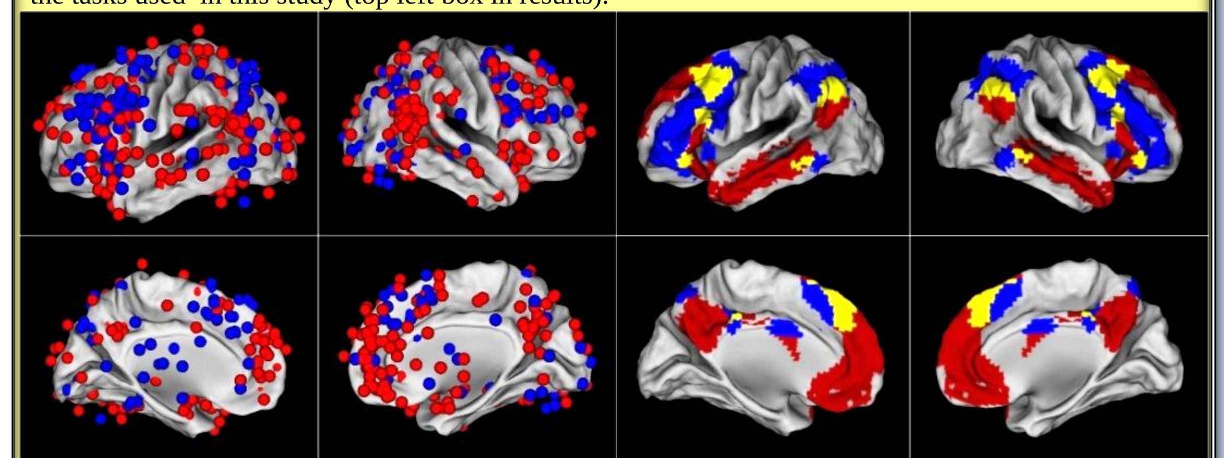
Meta-analysis of social and mechanical reasoning and resting-state networks

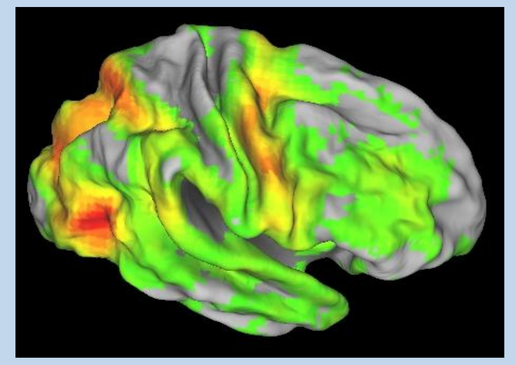
Meta-analyses reveal consistent clusters of activation foci for a range of socio-emotional tasks (red dots below e.g. TOM, emotion regulation tasks). These clusters are largely distinct from clusters associated with spatio-visual tasks (blue dots below), which are also highly consistent within domain (i.e. logic, mechanical / causal reasoning, math, executive function, working memory and intelligence tasks all produce similar patterns, *comparison of sub-domains not shown , see box to right for e.g.*).
In order to identify these two networks, we produced resting-state correlations which were seeded either by producing an averaged time course from all foci generated by socio-emotional tasks, or from all foci generated by higher spatio-visual reasoning tasks. The regions of separation and overlap on the right are generated by thresholding these correlation maps. Note the similarity with the findings from the tasks used in this study (top left box in results).



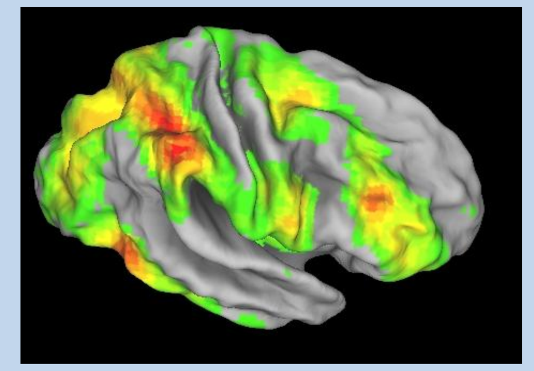
Red: social reasoning; Blue: numerical, logical, and analytic reasoning; Yellow: overlap.

Similar brain regions for eye movements and high level mechanical reasoning

Although a number of studies have contrasted social reasoning tasks with low level physical reasoning controls, few studies have looked at high level mechanical reasoning / physics. What brain regions does this recruit? Here we show a comparison between high level physical reasoning and a simple visuo-spatial attention task (a delayed saccade task). This task has a working memory component (which may drive the DLPFC activity in addition to the dorsal attention network), however is a basic task borrowed from the non-human primate literate which lacks any explicit content or higher reasoning component. Nonetheless, the similarity in brain regions recruited is striking.
These findings are in accordance with recent studies of mathematical reasoning which indicate that arithmetic relies upon some of the same basic spatial processing architecture which evolved for controlling eye movements (Knops et al., 2009). Similarly, very high level mathematical reasoning tasks (solving integral equations) also produce activity predominately localized within the dorsal attention network (Krueger et al., 2008).



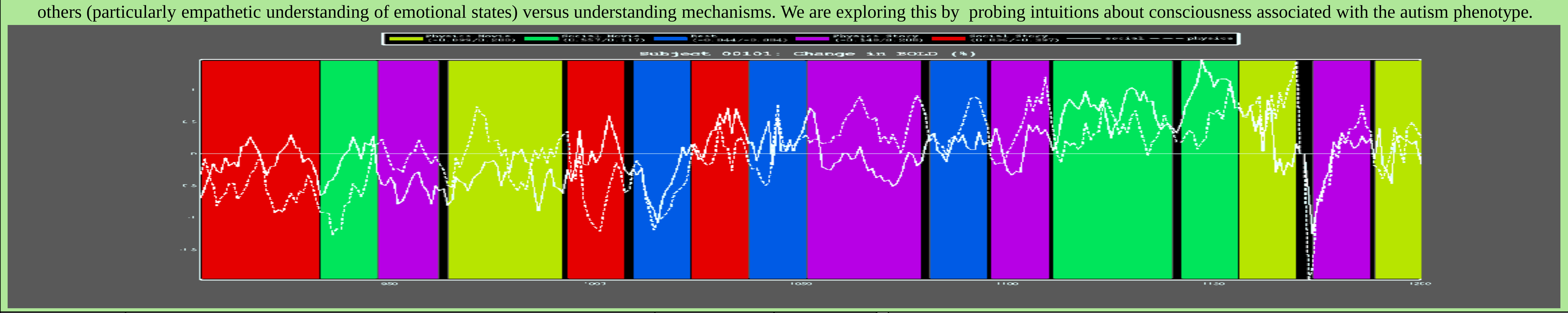
Delayed Saccade > Rest

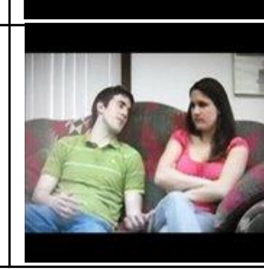


Physics > Social

A biological basis for the Mind-Body problem

Fox et al. (2005) and numerous studies of deactivations associated with effortful cognitive tasks suggest that the dorsal attention network and default areas have a push-pull relationship with each other, such that default areas tend to be less active when dorsal attention areas are more active, and vice versa (less so for autism S's). While it is common to interpret co-activation and high resting state correlations as markers of functional integration, little has been made of the functional significance of this finding. We suggest, and provide initial evidence here, that these findings reflects a functional segregation (or lack of integration) of core processes involved in socio-emotional cognition versus spatio-visual cognition. Below is a time course illustrating how activity in core social regions (solid line) and core mechanical regions (dotted line) vary as the participant undergoes various conditions. Blue corresponds to rest periods, red and green are social conditions, pink and yellow are physics conditions.
This functional segregation may provide a biological basis for our natural tendency to dualism (Bloom, 2004). More specifically, it may explain the 'problem of consciousness' i.e. the difficulty we have with viewing scientific accounts as fully explaining the mind / experience. We hypothesize that this 'explanatory gap' is a by-product of the functional segregation of systems which have evolved for understanding others (particularly empathetic understanding of emotional states) versus understanding mechanisms. We are exploring this by probing intuitions about consciousness associated with the autism phenotype.



CONDITION	STORY TEXT/MOVIE CLIP	QUESTION	ANSWER
Physics Story	A snowmobile is cruising over plains of white, hard packed snow. The driver steers the snowmobile in a straight line while at the same time pointing a flare gun straight into the air. The driver pulls the trigger, firing a bright flare into the air. Then, the driver immediately slams on his brakes. The flare flies through the air and then lands in the snow.	Will the flare land in front of the snowmobile?	Yes
Social Story	Sue sneaks into the kitchen, gets on a chair, and puts her little hand into the candy jar to grab a heaping handful of treats. As she walks out of the kitchen, she smirks at the thought of disobeying her mother, who told her not to have any more sweets. But as she brings the candy to her mouth a sinking feeling of guilt comes over her. She knows the candy is being saved for a party tomorrow. Conflicted, Sue finally decides to put the candy back and not eat any.	Does Sue's mother know that Sue has tried to sneak some candy?	No
Physics Movie		Would water flow if there was a large hole in the tube?	No
Social Movie		Does he think that she is angry?	No

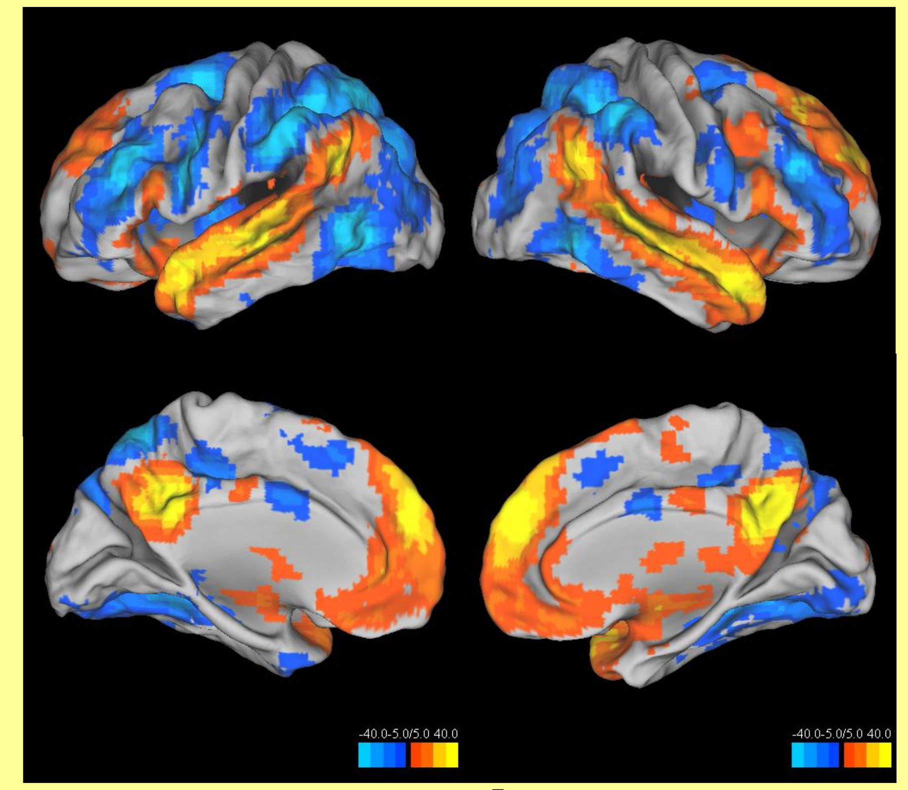
Behavioral Data

On average subjects performed better on the social condition (77.98% accuracy) as compared to the physics condition (63.26% accuracy), while performing similarly on the story condition (78.06% accuracy) and movie condition (70.21% accuracy).

CONDITION	AVERAGE SCORE
social movie	0.779166667
physics movie	0.625
social story	0.780555556
physics story	0.640277778
movie	0.702083333
story	0.710416667
social	0.779861111
physics	0.632638889

Correlations were also calculated by comparing each subject's accuracy between conditions. Correlations between conditions might be partially accounted for by variations each subject's general intelligence, e.g. the correlation between social conditions and physics conditions was 0.51. There was an interesting relationship between condition and presentation evinced by the strong correlations between the physics conditions to the movie conditions (.9219) and the social conditions to the story conditions (.9421), suggestive of a link between visual processing and mechanical reasoning (consistent with other findings here), and between narrative comprehension and social reasoning.

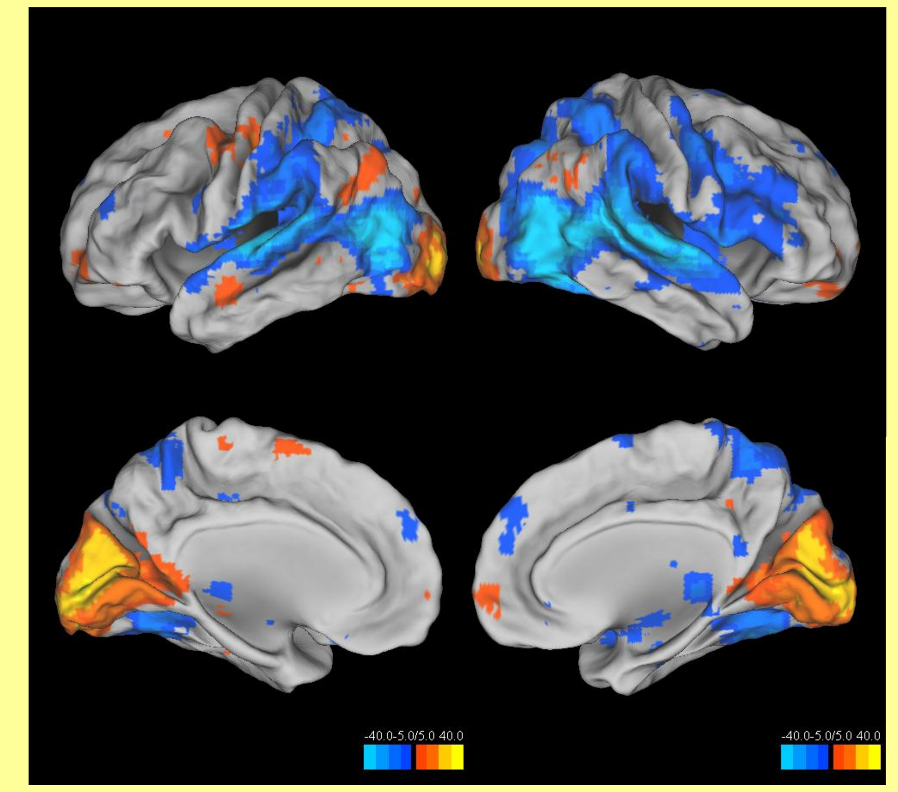
Results



social – physics

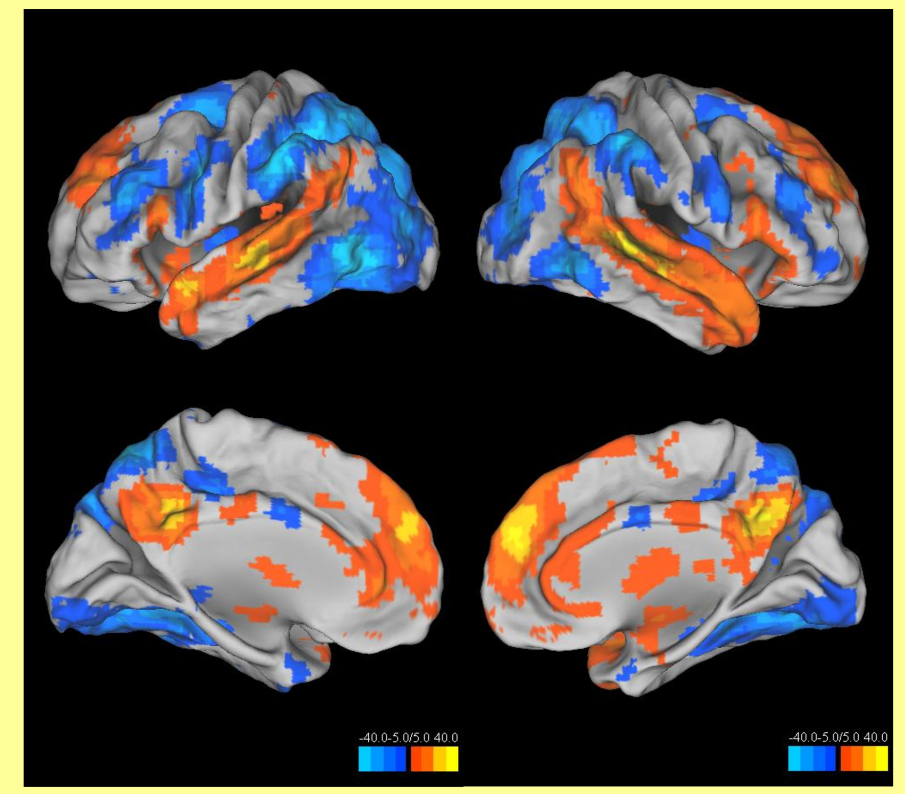
orange – social; blue– physics

All images are fixed effects analyses (n=9) threshold |z|>5, p<0.000001 uncorrected



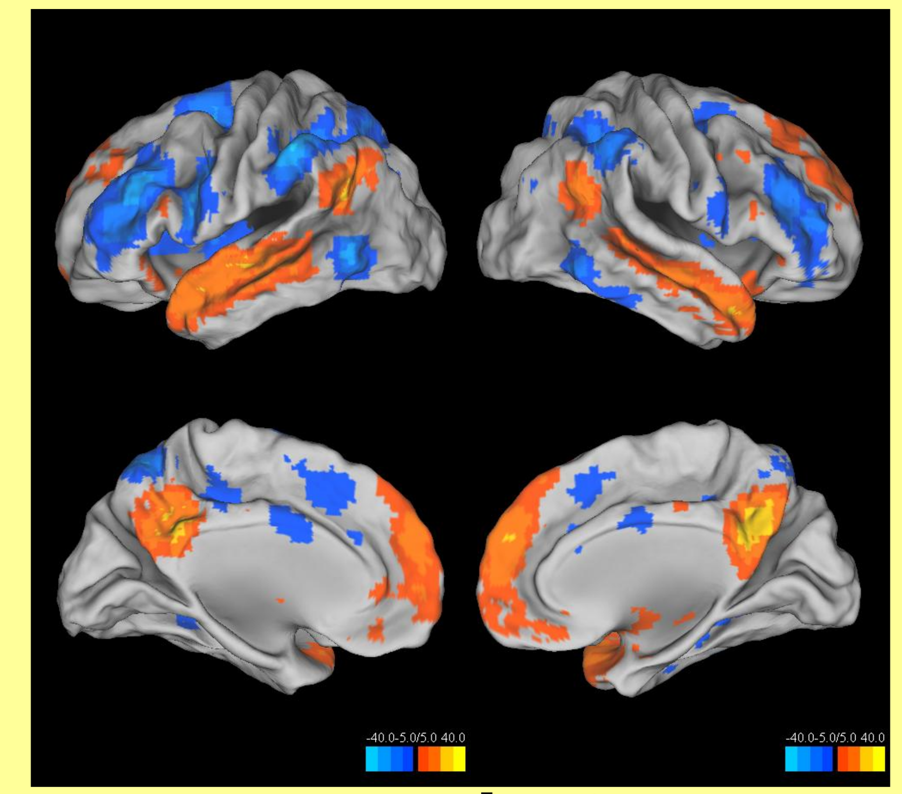
story - movie

orange – story; blue – movie



social movie – physics movie

orange –social movie; blue – physics movie



social story – physics story

orange – social story; blue - physics story

Conclusions

There were marked differences in the brain areas recruited by the social and mechanical reasoning tasks. Social reasoning conditions, regardless of presentation modality, recruited inferior medial parietal cortex, medial prefrontal cortex, right temperoparietal junction, and middle and superior temporal regions. Mechanical reasoning conditions, regardless of presentation modality, recruited intra-parietal sulcus, frontal eye fields, dorsal lateral prefrontal cortex, and lateral occipital area near MT.
The strength of the statistical comparisons is notable, and supports a view of these tasks as relying on largely distinct brain networks that bear a push-pull relationship to each other. It is further notable that, aside from regions involved in somato-motor function and early visual areas, much of the cortex is preferentially recruited by one or other domain. This pattern of results is not indicative of two closely matched tasks that differ only in a few cognitive components, but rather suggests two broadly different cognitive domains which can be reliably identified by different tasks in different modalities. The data therefore supports the 'common sense' hypothesis that social and mechanical reasoning are largely distinct cognitive domains. This work is part of a larger project that will explore the neural bases of individual differences in socio-emotional and spatio-visual cognition.

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