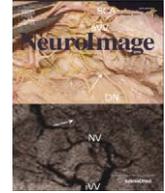




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## Highlights

### fMRI reveals reciprocal inhibition between social and physical cognitive domains

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► Physical reasoning tasks activate the TPN and deactivate the DMN. ► Social reasoning tasks deactivate the TPN and activate the DMN. ► Activated/deactivated regions match areas of maximal anti-correlation. ► Findings are not explained by task engagement, or internal vs. external attention. ► TPN versus DMN dichotomy reflects opposing cognitive modes.



# fMRI reveals reciprocal inhibition between social and physical cognitive domains

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## ABSTRACT

Two lines of evidence indicate that there exists a reciprocal inhibitory relationship between opposed brain networks. First, most attention-demanding cognitive tasks activate a stereotypical set of brain areas, known as the task-positive network and simultaneously deactivate a different set of brain regions, commonly referred to as the task negative or default mode network. Second, functional connectivity analyses show that these same opposed networks are anti-correlated in the resting state. We hypothesize that these reciprocally inhibitory effects reflect two incompatible cognitive modes, each of which is directed towards understanding the external world. Thus, engaging one mode activates one set of regions and suppresses activity in the other. We test this hypothesis by identifying two types of problem-solving task which, on the basis of prior work, have been consistently associated with the task positive and task negative regions: tasks requiring social cognition, i.e., reasoning about the mental states of other persons, and tasks requiring physical cognition, i.e., reasoning about the causal/mechanical properties of inanimate objects. Social and mechanical reasoning tasks were presented to neurologically normal participants during fMRI. Each task type was presented using both text and video clips. Regardless of presentation modality, we observed clear evidence of reciprocal suppression: social tasks deactivated regions associated with mechanical reasoning and mechanical tasks deactivated regions associated with social reasoning. These findings are not explained by self-referential processes, task engagement, mental simulation, mental time travel or external vs. internal attention, all factors previously hypothesized to explain default mode network activity. Analyses of resting state data revealed a close match between the regions our tasks identified as reciprocally inhibitory and regions of maximal anti-correlation in the resting state. These results indicate the reciprocal inhibition is not attributable to constraints inherent in the tasks, but is neural in origin. Hence, there is a physiological constraint on our ability to simultaneously engage two distinct cognitive modes. Further work is needed to more precisely characterize these opposing cognitive domains.

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## Introduction

The last decade has witnessed rapidly growing interest in the brain's task negative or default mode network (DMN<sup>1</sup>), both in health and disease (Andrews-Hanna, 2011; Broyd et al., 2009; Buckner et al., 2008).

The DMN is a constellation of regions that includes areas in medial parietal/posterior cingulate, medial prefrontal, lateral inferior parietal and superior temporal cortices. This network exhibits activity decreases during performance of a wide variety of tasks (Binder et al., 1999; Shulman et al., 1997). Tasks that deactivate the DMN also activate a second common network, the task positive network (TPN) (Fox et al., 2006; Fransson, 2005), which includes areas in dorsal parietal and lateral prefrontal cortices. Spontaneous activity in these two networks is temporally anti-correlated in the resting state (Fox et al., 2005, 2009). Thus, mutual antagonism between the DMN and the TPN is regularly observed both in the resting state and during task performance (Fox et al., 2005, 2009; Fransson, 2005; Golland et al., 2007; Greicius et al., 2003; Tian et al., 2007; Uddin et al., 2009). While some methodological concerns about the validity of anti-correlations that involve regression of the mean signal have been noted (Murphy et al., 2009), observations that don't use mean signal regression also identify anticorrelated regions (Chai et al., 2012; Chang and Glover, 2009; Fox et al., 2009). In addition, there is evidence that the hypothesized physiological inhibition is relevant to

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<sup>1</sup> DMN: Default Mode Network (Raichle et al., 2001)—also known as the task negative network (Fox et al., 2005)—network including midline and inferior parietal regions commonly deactivated during demanding cognitive tasks; TPN: Task Positive Network (Fox et al., 2005)—network including parietal and frontal areas which is anti-correlated with the DMN and which is commonly activated during demanding cognitive tasks. The TPN overlaps the DAN and FCPN. DAN: Dorsal Attention Network (Fox et al., 2006)—network defined by positive resting state functional connectivity which includes regions involved in visual attention. Network includes much of intra-parietal and pre-central sulci. FPCN: Fronto-parietal Control Network (Vincent et al., 2008)—network defined by positive resting state connectivity which includes regions involved in problem solving, working memory and executive functions. Much of the network lies directly anterior to the DAN in parietal and frontal cortices.

understanding performance in normal (Gordon et al., 2007) and diseased states (Fassbender et al., 2009; Kennedy, 2006; Lustig et al., 2003; Pomarol-Clotet et al., 2008). As a result, it has been suggested that the anti-correlation between networks may prove functionally more important than DMN activity itself (Broyd et al., 2009; Fox et al., 2005; Uddin et al., 2009). The goal of this investigation is to shed light on the cognitive significance of this tension between the TPN and DMN.

### Cognitive significance of DMN vs TPN dichotomy

The relationship between the TPN and DMN has been likened to a two sided see-saw, such that activity in one network decreases below baseline as activity in the other increases above baseline (Meyer et al., 2012). This analogy is wholly consistent with findings from resting state functional connectivity analyses. However, evidence from task-based studies most clearly supports only one half of the full range of motion of the see-saw: activity in the TPN parametrically increases in activation in response to cognitive effort or task demand, while the DMN shows parametric decreases (Gordon et al., 2007; Mason et al., 2007; McKiernan et al., 2003). Demonstrations of the converse pattern, in which the DMN is activated and TPN deactivated, have been much more elusive. Accounting for this asymmetry represents a significant theoretical opportunity, as there are a number of competing accounts which critically depend on characterizing the processes which lead to activation of the DMN and deactivation of the TPN. We consider three broad hypotheses which might account for the relationship between the TPN and DMN: two that are frequently mentioned in the literature on the default network, and a third which derives from a distinct literature. The first hypothesis is that the relationship between the TPN and DMN reflects a tension between goal-directed cognition versus spontaneous cognition or mind-wandering. The second hypothesis is that this relationship reflects a tension between externally versus internally directed attention. The third hypothesis is that it reflects a tension between distinct cognitive modes associated with social and non-social domains. The motivation and evidence for these hypotheses will be briefly reviewed.

#### Goal directed vs. spontaneous cognition

The first hypothesis is directly related to the “task-positive” and “task negative” (or “default mode”) labels, which have come to be associated with the two networks (Raichle et al., 2001). These labels were suggested by early findings that a broad range of tasks activate the TPN and deactivate the DMN (Shulman et al., 1997). This hypothesis predicts that it should not be possible to identify goal-directed tasks that activate the DMN and/or deactivate the TPN. It is challenged by more recent findings that identify goal-directed tasks which activate the DMN above a resting baseline (Iacoboni, 2004; Sestieri et al., 2010; Spreng et al., 2010), including one task which demonstrates parametric increases in DMN activity associated with social working memory load (Meyer et al., 2012). Hence Spreng (2012) suggests that the labels ‘task positive’ and ‘task negative’ are “more likely the byproduct of the desire for rigorously controlled experimental designs (i.e., externally directed stimuli) than meaningful descriptors of functional brain networks.”

#### Internal vs. external attention

The second hypothesis appeals to attention to account for the tension between the TPN and DMN (Broyd et al., 2009; Buckner and Carroll, 2007; Buckner et al., 2008). These accounts build on the observation that a common feature of tasks that activate the TPN and deactivate the DMN is focused attention to the external environment. According to various accounts, focused attention may be in competition either with broad exploratory attention (Gilbert et al., 2007), or with a variety of types of internal attention, including attention to self (Andrews-Hanna, 2011; Fransson, 2006; Gusnard, 2001), conceptual association (Bar, 2009; Binder et al., 1999), episodic retrieval (Buckner and Carroll, 2007), and mental simulation or model building (Spreng et al., 2010). One study has presented evidence for both activation of

DMN regions and deactivation of TPN regions (Spreng et al., 2010). On this basis, the authors argue for a variant of the internal versus external attention account. The TPN comprises regions which lie in two distinct networks, as defined by positive functional connectivity: the dorsal attention network (DAN) and the fronto-parietal control network (FPCN). On this basis, Spreng (2012) argues the TPN does not represent a unitary functional network, but rather reflects distinct cognitive factors which are confounded in many tasks. Hence, Spreng argues that the tension between the TPN and the DMN as a ‘false dichotomy.’ Instead, Spreng suggests that the true tension lies between the DAN and the DMN, and reflects “competition between exogenous and endogenous loci of information processing.” However, this account runs into three difficulties. First, findings from resting state functional connectivity indicate that the regions which are most anti-correlated with the DMN lie in both the FPCN and the DAN.<sup>2</sup> Since these analyses are neutral with regard to task, the value of characterizing the TPN as a network in tension with the DMN cannot be explained away by appeal to task confounds. Second, there have not been any demonstrations of goal-directed tasks which activate the DMN while deactivating the entire TPN. Spreng et al. (2010) show deactivation of the DAN alongside activation of both the DMN and FPCN. However, that study does not identify specific deactivated regions, and therefore does not demonstrate alignment between task induced activations/deactivations and anti-correlated regions derived from functional connectivity. Third, the cognitive characterization of the tension as being due to internal versus external attention appears problematic for one class of tasks which have been consistently associated with the DMN. A large number of studies have implicated the DMN in social cognition (Amodio and Frith, 2006; Mars et al., 2012; Schilbach et al., 2008; Van Overwalle, 2009). Many of these tasks differ from other tasks which are classified as involving internally directed cognition in a significant respect: they require attention to external stimuli. For instance, Iacoboni (Iacoboni, 2004) finds activation of the default network above resting levels while participants watch videos of unfamiliar individuals engaged in social interactions. Social cognition tasks may essentially involve attention to ‘internal states’, however, these are often the ‘internal states’ of unfamiliar individuals, not of the participant.

#### Opposing domains

The third hypothesis, which we favor, is the ‘opposing domains hypothesis’. According to this hypothesis, the task positive and task negative networks reflect two incompatible cognitive modes, each of which can be directed towards understanding the external world. Instead of appealing to attention, this hypothesis is more closely allied to dual-process models of cognition, which hold that distinct cognitive modes can be engaged by externally directed tasks (Evans, 2003; Kahneman, 2003; Sloman, 1996). These modes are hypothesized to be associated with two broad cognitive domains, namely social information processing (reasoning about the minds of others) and non-social information processing (reasoning about physical objects). The opposing domains hypothesis is motivated by theoretical work in a distinct literature on the problem of consciousness (Hill, 1997; Jack and Shallice, 2001; Levine, 2000; Nagel, 1974; Robbins and Jack, 2006), however for current purposes we focus on considering this hypothesis as a candidate for explaining the tension between the TPN and DMN. A direct prediction of both this hypothesis and the internal vs. external attention hypothesis is that, in addition to tasks that activate the task positive network and deactivate the task negative network, it should also be possible to identify goal-directed tasks that activate the task negative network and deactivate the task positive network. In

<sup>2</sup> While the TPN was aligned with the dorsal attention network in Fox et al.’s initial papers (Fox et al., 2005, 2006) the spatial characterization of the TPN in those analyses was constrained both by negative correlations with seeds in the DMN and by positive correlations with points generated by studies of visual attention. Later studies have more simply identified areas which are negatively correlated with DMN seeds (Chai et al., 2012; Chang and Glover, 2009; Fox et al., 2009). These regions do overlap the FPCN.

190	other words, it should be possible to identify goal directed tasks that push	hypothesis, we made the social texts significantly longer than the me-	253
191	the see-saw to both extremes of its full range of motion. Further, since the	chanical texts, while holding reading difficulty constant.	254
192	definition of the TPN and DMN was initially established by reference to		
193	anti-correlated networks seen in resting connectivity (Fox et al., 2005),	<b>Materials and methods</b>	255
194	there should be a close correspondence between these anti-correlated		
195	networks and the regions shown to be in tension by the tasks. The key dif-	<i>Social and mechanical reasoning study</i>	256
196	ference between these hypotheses is that the internal vs. external atten-		
197	tion hypothesis predicts this pattern should be produced by external	<i>Participants</i>	257
198	and internal tasks, even when the social processing demands of the	Forty-five student volunteers were paid \$50 to participate. The ma-	258
199	tasks are similar. In contrast, the opposing domains hypothesis predicts	majority (43/45) of participants were recruited from a separate behavioral	259
200	that this pattern should be produced by social and non-social tasks,	study of individual differences in social and non-social reasoning. All	260
201	even when the attention demands of the tasks are similar. We know of	participants were drawn from the undergraduate population of Case	261
202	no reports which test the first prediction, as existing reports confound in-	Western Reserve University. All participants were fluent English	262
203	ternal focus with social processing (Sestieri et al., 2010; Spreng et al.,	speakers and reported no history of neurological or psychiatric disor-	263
204	2010). The present study aims to test the second prediction.	ders. All participants had normal or corrected to normal vision and nor-	264
		mal hearing. The mean age of the participants was 20.5 years (range of	265
		19–23 years), with 24 female participants. Informed consent was	266
205	<i>Experimental design</i>	obtained in accordance with guidelines provided by the institutional re-	267
		view board of Case Western Reserve University Hospitals.	268
206	To test our hypothesis, we designed tasks which were specific in terms	<i>Magnetic resonance imaging</i>	269
207	of which domain they recruited from, but not in terms of the processes	Scans were collected using a 4 T Bruker-Siemens hybrid MR scanner.	270
208	they recruited from a given domain. The motivation for this approach fol-	Participants underwent an MP-RAGE high resolution anatomical scan,	271
209	lows from two considerations. First, there already exist carefully con-	T2 weighted anatomical scan, and five functional task runs (300 vol-	272
210	trolled studies which have shown that social and physical reasoning are	umes each). Functional runs used an echoplanar imaging sequence	273
211	associated with distinct brain areas (Martin and Weisberg, 2003;	with 38 contiguous 3.8 mm slices, 3.8 × 3.8 mm in-plane resolution,	274
212	Mitchell, 2002). However, these studies did not find evidence of activa-	TE = 20 ms, flip angle = 90°, TR = 2.00 s. Participants practiced a train-	275
213	tion and deactivation relative to baseline consistent with the opposing do-	ing version of the task during their MPRage.	276
214	main hypothesis. We hypothesize that this pattern was not observed		
215	because the tasks only required processing of surface features (e.g., pat-	<i>Stimulus presentation</i>	277
216	terns of movement, or semantic associations between two words). They	Stimuli were presented using E-prime2.0 software. Images were	278
217	did not require participants to represent the mental states of identifiable	projected onto a screen attached to the head coil using an Avotech projec-	279
218	conspicuous, nor encourage participants to apply principles of physics in	tor and were viewed by subjects through a mirror. Sound was presented	280
219	order to understand mechanical processes. Two recent reviews of work	though integrated Avotech headphones. Participants responded to stimuli	281
220	in social cognitive neuroscience argue that the desire to produce rigour-	using an Avotech MR compatible serial response system by pressing one	282
221	ously controlled studies has encouraged the use of task designs that are too	of two buttons using either the index or middle finger of the right hand.	283
222	artificial to shed light on many important social cognitive processes		
223	(Schilbach et al., in press; Zaki and Ochsner, 2012). Rather than design-	<i>Design</i>	284
224	ing our tasks to distinguish distinct process involved in social or mechani-	We used a two factor crossed design to examine the cortical regions	285
225	cal reasoning, we used ecologically valid tasks designed to engage rich	recruited during social and scientific reasoning, using problems	286
226	mechanical and mental state representations. For example, our social texts	presented in two different modalities: text, and video with audio	287
227	were modified from a prior study of false belief by adding additional em-	soundtrack. Each 10 minute scanner run consisted of 16 trials (4 pre-	288
228	otional and moral content, producing narratives similar to soap opera	sentations of each of the 4 conditions) and 4 rest periods, all 27 s in	289
229	(Appendix B). Second, some studies have demonstrated co-activation of	length. The order of stimuli and rest periods within each scanner run	290
230	the DMN and regions in the TPN (Meyer et al., 2012; Spreng et al.,	was determined randomly for each participant. Variable fixation pe-	291
231	2010). According to the opposing domains hypothesis, this could occur	riods of 1, 3, or 5 second duration separated each question or rest period	292
232	because these studies involved cognitive components associated with	from the next. On each trial, participants had 20 s to either read a text	293
233	both of the two distinct cognitive modes. Hence, a key goal of this study	passage or watch a video. A short yes/no textual comprehension ques-	294
234	was to identify tasks which predominantly recruit processes associated	tion was then presented on screen and participants were given 7 s to re-	295
235	with just one of these cognitive modes.	spond. All text passages and videos were unique and were not repeated.	296
236	The experimental tasks followed a 2 × 2 factorial design with cognitive	A brief description of the five conditions (including rest) follows:	297
237	domain and perceptual modality as crossed factors (Fig. 1). On each trial,		
238	after reading the text or watching the video clip for 20 s, a simple yes/no	<i>Social text condition</i>	298
239	question was presented as text and participants were given 7 s to answer	The social reasoning texts were adapted from (Saxe and Powell,	299
240	by pressing a key (Fig. 2). The social videos depicted conversations be-	2006) and elaborated to add additional emotional and moral context	300
241	tween two individuals who often misunderstood each other. The ques-	to the existing false belief content. Questions concerned the beliefs or	301
242	tions concerned one actor's belief about the emotional state of the other	attitudes of one of the protagonists. Texts had a Flesch Reading Ease	302
243	actor. The social texts were adapted from a prior study (Saxe and	score of 77.8 and Flesch Grade Level of 6.0. Average word counts were	303
244	Powell, 2006) and described scenarios in which at least one protagonist	as follows: story text: 86.2 question text: 9.5 total: 95.7. All items are	304
245	had a false belief. The questions tested understanding of this false belief.	listed in appendix B.	305
246	The mechanical videos were clips excerpted from the Video Encyclopedia		
247	of Physics (Education Group and Associates, 1995). The questions were	<i>Social video condition</i>	306
248	counterfactuals that tested understanding of the illustrated physical prin-	The social reasoning videos were generated by Angela Ciccia, Dept.	307
249	ciple. The mechanical texts described puzzles similar to and adapted from	of Psychological Sciences, Case Western Reserve University, using stu-	308
250	examples found in popular scientific puzzle books. The questions asked	dent actors. Each video comprised an emotionally laden verbal ex-	309
251	participants to predict what would happen next. To disambiguate the op-	change between two individuals, one male and one female, which	310
252	posing domains hypothesis from the external vs. internal attention		

Condition	Stimulus	Question	Answer
Mechanical 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
Mechanical Movie		Would water flow if there was a large hole in the tube?	No
Social Movie		Does he think that she is angry?	No

Fig. 1. Schematic illustration of task conditions.

311 typically involved a degree of misunderstanding. There were no direct  
 312 linguistic cues used to demonstrate the emotion/construct of interest  
 313 thereby requiring the participant to rely on extralinguistic and emotional  
 314 cues to answer the emotional state question. Actors were filmed  
 315 against one of two plain backgrounds to limit distraction. All questions  
 316 focused on whether one protagonist understood the attitude or emotional  
 317 states of the other protagonist.

#### 318 Mechanical text condition

319 The mechanical reasoning texts were adapted from public domain  
 320 science puzzles. Persons often featured in the descriptions. Texts had a  
 321 Flesch Reading Ease score of 77.0 and Flesch Grade Level of 6.0. All questions  
 322 asked whether or not a specific event would happen next. Average  
 323 word counts were as follows: story: 75.3 question: 9.6 total: 84.9. All  
 324 items are listed in Appendix B.

#### 325 Mechanical video condition

326 The mechanical reasoning videos consisted of clips taken, with permission,  
 327 from the Video Encyclopedia of Physics. Each clip

demonstrated a mechanical principle or phenomenon. The phenomenon was also described in a voiceover audio track. Many clips featured  
 329 actors. Questions were designed to test understanding of the mechanical  
 330 principle explained, with most questions phrased as counterfactuals. 331

#### Rest condition

The rest condition involved the passive viewing of a red fixation cross centered on a black background. 332 333 334

#### Imaging analysis (task data)

A scanner specific atlas target was created from the MP-RAGE images of 25 young adults (Buckner et al., 2004). The resulting atlas represented Talairach space according to the SN method (Lancaster et al., 1995). After calculation of parameters for realignment within each BOLD run, and for coregistration of each BOLD run with the atlas aligned T1 and T2 structural images, BOLD stacks were resampled directly from the raw data into a 3 mm cubic voxel atlas space. Each BOLD stack was then spatially smoothed with a Gaussian 3D filter with FWHM of 2 voxels (6 mm). 335 336 337 338 339 340 341 342 343 344

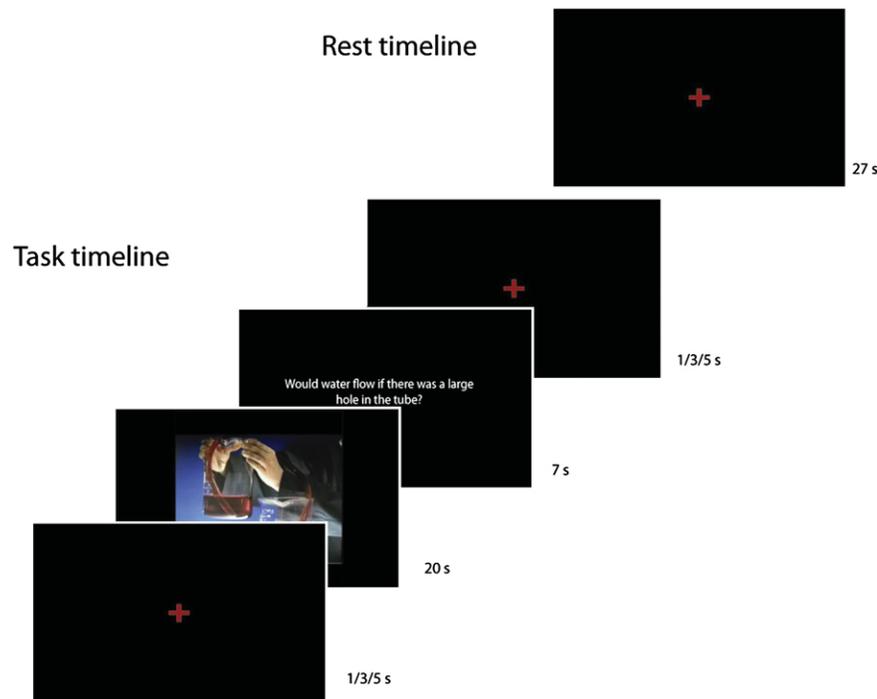


Fig. 2. Timeline for tasks and resting trials.

345 Data for each subject were entered into a general linear model in  
 346 which baseline and linear trend were estimated alongside a single  
 347 uniform assumed response associated with each condition. Voxel ac-  
 348 tivity was averaged and activity in each given condition was  
 349 subtracted from baseline or another condition using the Washington  
 350 University of Saint Louis software application fidl. The computerized  
 351 anatomical reconstruction and editing toolkit, Caret, (Washington  
 352 University in Saint Louis software) was used for visualization.

### 353 Resting state functional connectivity

354 Resting state data was retrieved from the public database NITRC  
 355 on February 15, 2010. Two data sets were used: Beijing\_Zang (Zang,  
 356 Y.F.; n = 198 [76 M/122 F]; ages: 18–26; TR = 2; # slices = 33;  
 357 # timepoints = 225) and Cambridge\_Buckner (Buckner, R.L.; n = 198  
 358 [75 M/123 F]; ages: 18–30; TR = 3; # slices = 47; # timepoints = 119).  
 359 The total combined number of subjects was 396 (245 females), aged  
 360 18–30 (mean age 21.1). The data was aligned to the same atlas space  
 361 as the task data (711–2B), and smoothed to 6 mm FWHM. Analysis  
 362 methods were identical to those previously reported (Fox et al., 2005,  
 363 2009), with two exceptions: (i) no global (whole brain) regressor was  
 364 used (i.e. only movement, white matter and ventricle regressors were  
 365 used), unless otherwise specified. (ii) All statistical contrasts used a ran-  
 366 dom effects method (i.e. one Fisher-z transformed correlation image per  
 367 subject was entered into a single sample t-test), and the resulting statisti-  
 368 cal images were corrected for multiple comparisons.

## 369 Results

### 370 Behavior

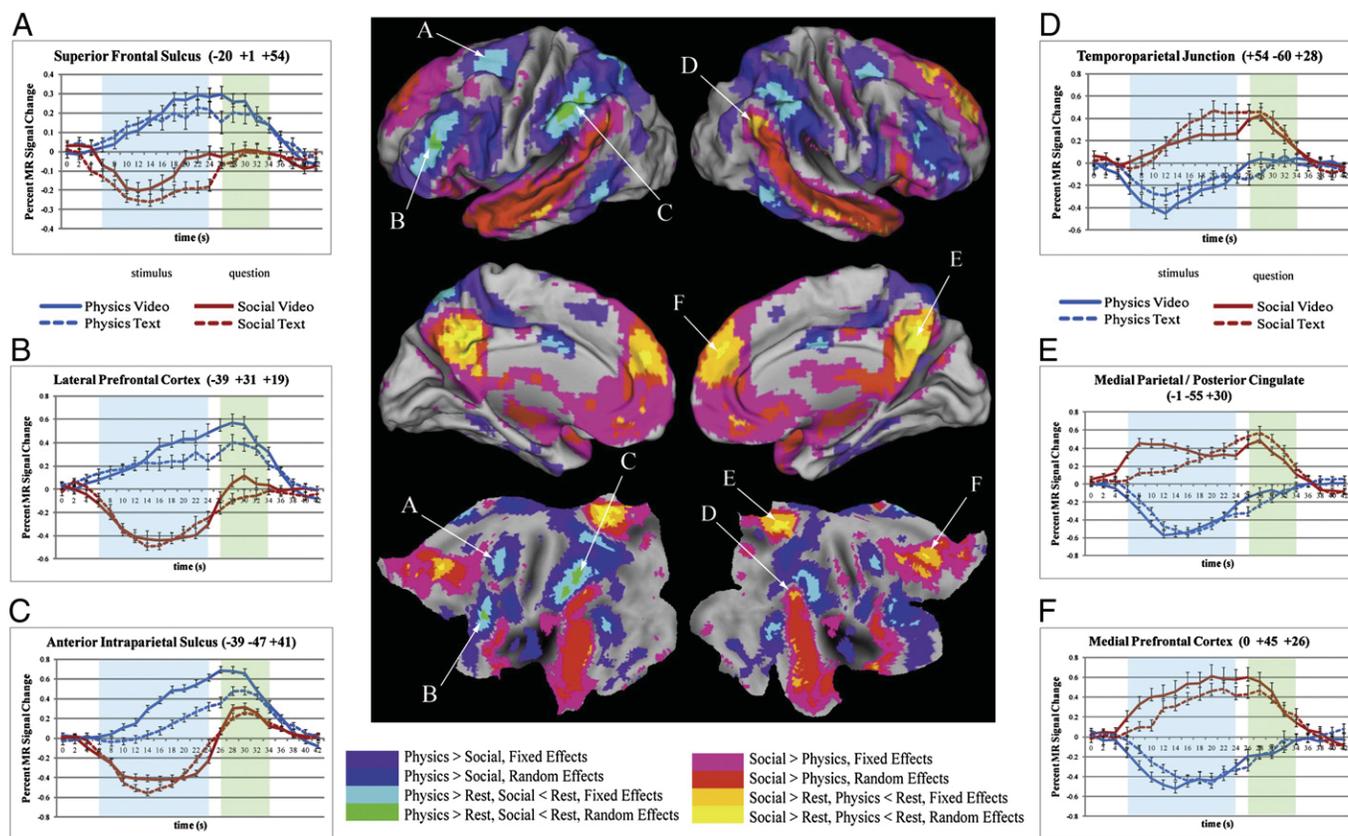
371 Mean accuracy for the four conditions was as follows: Social  
 372 movies 85.3%; Mechanical movies 71.7%, Social texts 80.4%, Mechan-  
 373 ical texts 65.7%. fMRI analyses that control for task difficulty are  
 374 reported below the primary analyses.

fMRI

375

The fMRI data were analyzed using the method of strict cognitive  
 conjunction: We report regions as sensitive to domain only when the  
 contrast between social and mechanical tasks was statistically signifi-  
 cant independently within each modality (text and video) (Friston et  
 al., 2005; Nichols et al., 2005). Regions more associated with the social  
 tasks (Fig. 3, warm colors) overlapped substantially with the DMN.  
 These regions in medial prefrontal, medial parietal/posterior cingulate,  
 lateral parietal and superior temporal cortices have also been identified  
 in prior studies of social cognition (Amodio and Frith, 2006), emotion  
 identification (Phan, 2002), and autobiographical memory (Buckner  
 and Carroll, 2007). Regions more associated with mechanical reasoning  
 (Fig. 3, cool colors) overlapped substantially with the TPN, including re-  
 gions in both the DAN and the FPCN. These regions in dorso-lateral pa-  
 rietal and lateral prefrontal cortex have been identified in studies of  
 abstract reasoning (Vincent et al., 2008), action observation and execu-  
 tion (Van Overwalle and Baetens, 2009), visual attention and working  
 memory (Corbetta and Shulman, 2002; Fox et al., 2006; Owen et al.,  
 2005). These findings are also consistent with prior studies that used  
 closely controlled stimuli to contrast social and physical reasoning  
 (Martin and Weisberg, 2003; Mitchell, 2002), except that the areas  
 identified by contrasting our tasks were far more extensive. Fixed and  
 random effects analyses were used to obtain upper and lower estimates  
 of the extents of cortex sensitive to cognitive domain. Even using the  
 statistically highly conservative (Friston et al., 2005) method of strict  
 cognitive conjunction (Nichols et al., 2005), in our sample of 45 partic-  
 ipants, we found 54% of the cortical surface to be sensitive to domain  
 (fixed effects result). Generalizing to the population, 21% of the cortical  
 surface was sensitive to domain (random effects result). Peak coordi-  
 nates from the random effects analysis can be found in Appendix A.

These observations serve to validate the tasks used by demonstrat-  
 ing that they preferentially recruit the hypothesized networks. As  
 might be predicted, our ecologically valid and engaging tasks produced  
 a far more extensive differentiation of brain regions than prior studies  
 which either aimed to identify specific processes and/or which  
 employed closely matched stimuli. However, direct contrasts between



**Fig. 3.** Brain areas sensitive to cognitive domain and antagonistic areas. Colored areas pass multiple comparison correction in both video and text conditions independently. Warm colors (pink, red, orange, yellow) activate more for social than mechanical reasoning. Cool colors (purple, blue, cyan, green) activate more for mechanical than social reasoning. Bright colors (orange, yellow, cyan, green) identify antagonistic areas, which are significantly above rest for both tasks in one domain, and significantly below rest for both tasks in the other domain. Contrasts in each domain are cumulative, i.e. mechanical areas in blue have passed the contrast for purple (Physics > Social, fixed), areas in cyan have passed for purple and blue, and areas in green have passed for purple, blue and cyan. Graphs A-F show timecourses from antagonistic areas, without correction for hemodynamic lag. Blue and green shading indicate time points associated with stimulus and response periods, respectively. Error bars show standard error of mean across participants. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

tasks cannot address the critical question at issue, of whether these tasks activated brain regions associated with one network above baseline, while deactivating regions associated with the other network.

#### Reciprocal suppression

To provide evidence for activation and deactivation, it is necessary to compare brain activity with a well-defined resting baseline. Our study combined two techniques to ensure a robust estimate of the resting baseline: brief variable delay periods between trials (1, 3 or 5 s), and the introduction of a fifth trial type, equal in frequency and duration (27 s) to the four experimental trial types, but consisting entirely of resting fixation. As a result, 28% of fMRI time was spent in resting fixation. We estimated activity relative to rest in two ways. First, we used the same assumed hemodynamic response function to model the task conditions and the resting fixation condition. We then identified regions that demonstrated a consistent pattern of activation and deactivation illustrative of reciprocal inhibition. That is, we identified voxels where each of the four contrasts (mechanical text-rest), (mechanical video-rest), (rest-social text), (rest-social video) were significantly positive, and where all four were significantly negative (alpha for each contrast  $p < 0.05$  two tailed, multiple comparison corrected, alpha for conjunction  $p < 6.25 \times 10^{-6}$ ). We found such regions ('antagonistic brain areas') throughout both the social reasoning and the mechanical reasoning networks (bright colors in Fig. 3). The second analysis addressed an important methodological concern with the first analysis: The baseline may not have been properly estimated if the assumed hemodynamic response function failed to capture all task related activity.

Hence, we generated a second set of models in which we made no assumptions about the hemodynamic response. This model estimated activity associated with each of the four experimental trial types on a frame-by-frame basis. In this model, both the variable delays between tasks and the resting fixation trials contributed to the baseline estimate. The timecourses in antagonistic areas derived from this model are shown in Figs. 3(A-F). They start at and return to baseline levels, and clearly demonstrate deviations above and below the baseline. This demonstrates that the antagonistic brain areas exhibit genuine deviations from the resting baseline.

#### Correspondence with resting state anti-correlations

The dichotomy between TPN and DMN regions was originally based on the observation that activity in these networks is negatively correlated at rest, when cognition is unconstrained by any task (Fox et al., 2005). If the opposing domains hypothesis correctly characterizes the cognitive tension between these networks, then there should be a close correspondence between our task-based antagonistic regions and anti-correlated regions. To examine this hypothesis, we performed a functional connectivity analysis on resting state data from a separate group of 396 participants, who were not exposed to our tasks. First, we used the methods of Fox et al. (2009), which involves removal, by regression, of the signal averaged over the whole brain. This analysis revealed extended areas of negative correlation that broadly corresponded to the regions revealed by the strict conjunction contrast between social and mechanical tasks. However, the results obtained with this method might overestimate the degree

463 to which brain areas are truly antagonistic. It has been shown that  
 464 global signal regression can produce negative correlations between  
 465 regions believed to lack inhibitory connections (Murphy et al.,  
 466 2009). Therefore, we performed a second, more conservative, analysis  
 467 omitting global signal regression (Chai et al., 2012; Chang and Glover,  
 468 2009). This highly conservative approach greatly reduced the extent  
 469 of the observed negative correlations, revealing only the most  
 470 anti-correlated areas. The correspondence between these maximally  
 471 anti-correlated areas and the antagonistic areas was remarkable  
 472 (Fig. 4). Areas anti-correlated with the mechanical network had a  
 473 whole brain spatial correlation of  $r=0.92$  with regions activated by  
 474 the social tasks and deactivated by the mechanical tasks. Areas  
 475 anti-correlated with the social network had a whole brain spatial cor-  
 476 relation of  $r=0.91$  with regions activated by the mechanical tasks  
 477 and deactivated by the social tasks. Hence, the antagonistic areas  
 478 identified using social and mechanical reasoning tasks corresponded  
 479 almost perfectly with the brain areas demonstrating the most robust  
 480 RS-fcMRI anti-correlations.

#### 481 Additional analyses

482 A number of additional analyses were conducted to rule out po-  
 483 tential confounds, detailed below.

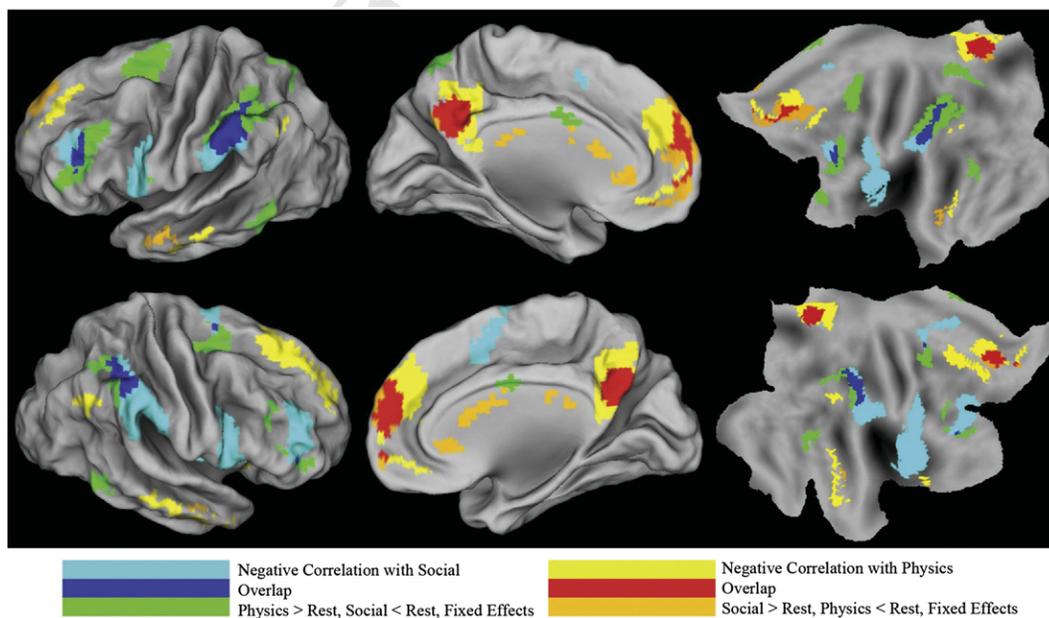
#### 484 Visual attention demands

485 Our first concern was that activation of parietal and frontal areas  
 486 associated with visual attention might be driven by differences in vi-  
 487 sual attention demands. Visual attention demands are influenced by a  
 488 variety of factors (e.g., eye-movements, covert attention, object track-  
 489 ing, contrast, crowding), which precludes quantification of the global  
 490 visual demands involved in viewing complex visual stimuli such as  
 491 the videos. On the other hand, the visual demands of text stimuli  
 492 are independent of content. The social and mechanical texts were  
 493 matched in terms of overall reading difficulty, font and other visual  
 494 properties; however the length of the texts varied. The number of  
 495 words therefore served as a direct index of the visual demands asso-  
 496 ciated with each text stimulus. We examined the effect of text length

497 by performing a median split on each of the two text conditions. We  
 498 then compared the shorter texts with the longer texts (mean differ-  
 499 ence = 9 words). This contrast did not produce any differences that  
 500 passed whole brain correction, however lowering the threshold and  
 501 looking at regions of interest revealed more activity for longer texts  
 502 in areas associated with mechanical cognition. Fig. 5 illustrates the  
 503 overall effect of text length in the social and mechanical networks  
 504 (defined by random effects strict conjunction). Social regions were  
 505 consistently less active for longer texts in both conditions. Mechanical  
 506 regions were more active for longer texts in the mechanical reasoning  
 507 condition. We had anticipated this association when designing the  
 508 stimuli. Therefore we made the visual demands greater in the social  
 509 condition by making the social texts longer, on average, than the me-  
 510 chanical texts (mean difference = 11 words). Therefore, the visual de-  
 511 mands in the text conditions drove activity in the opposite direction  
 512 to the effect of domain. Since areas reported here as preferring one  
 513 domain to another independently passed multiple comparison cor-  
 514 rection for the text stimuli in addition to the video stimuli, we can  
 515 rule out the possibility that the preference of regions in the dorsal at-  
 516 tention network for mechanical cognition is due to differences in vi-  
 517 sual attention demands.

#### 518 Action observation and execution

519 A second potential confound relates to brain areas in lateral  
 520 intra-parietal and inferior pre-central sulcus that are associated  
 521 with action observation and execution (Van Overwalle and Baetens,  
 522 2009). These areas were more active in the mechanical than the social  
 523 conditions. This could not be due to differences in action execution, as  
 524 the response requirements were identical for social and mechanical  
 525 conditions. Therefore, we audited the conditions for differences in ac-  
 526 tion observation. In the social videos, two people were on screen  
 527 throughout, continually engaged in speech acts, gestures and emo-  
 528 tional expressions. In the physics videos, people or body parts were  
 529 only occasionally visible. A count was made of the number of physical  
 530 actions involving the limbs (i.e. not including speaking and facial ex-  
 531 pressions) and the length of time they occupied. No significant differ-  
 532 ences in the number or time spent performing actions were found



**Fig. 4.** Correspondence between antagonistic areas derived using task induced deviations from rest and anti-correlations networks derived from resting functional connectivity (without regressing whole brain signal). All areas corrected for multiple comparisons. Resting connectivity data from a separate group of subjects was used to derive regions anti-correlated with social antagonistic areas, and separately with mechanical antagonistic areas. The overlap of these anti-correlated areas with antagonistic areas is shown. Core brain areas involved in social reasoning tend to suppress core regions involved in mechanical reasoning, and vice-versa, even during unconstrained thought in the absence of a task.

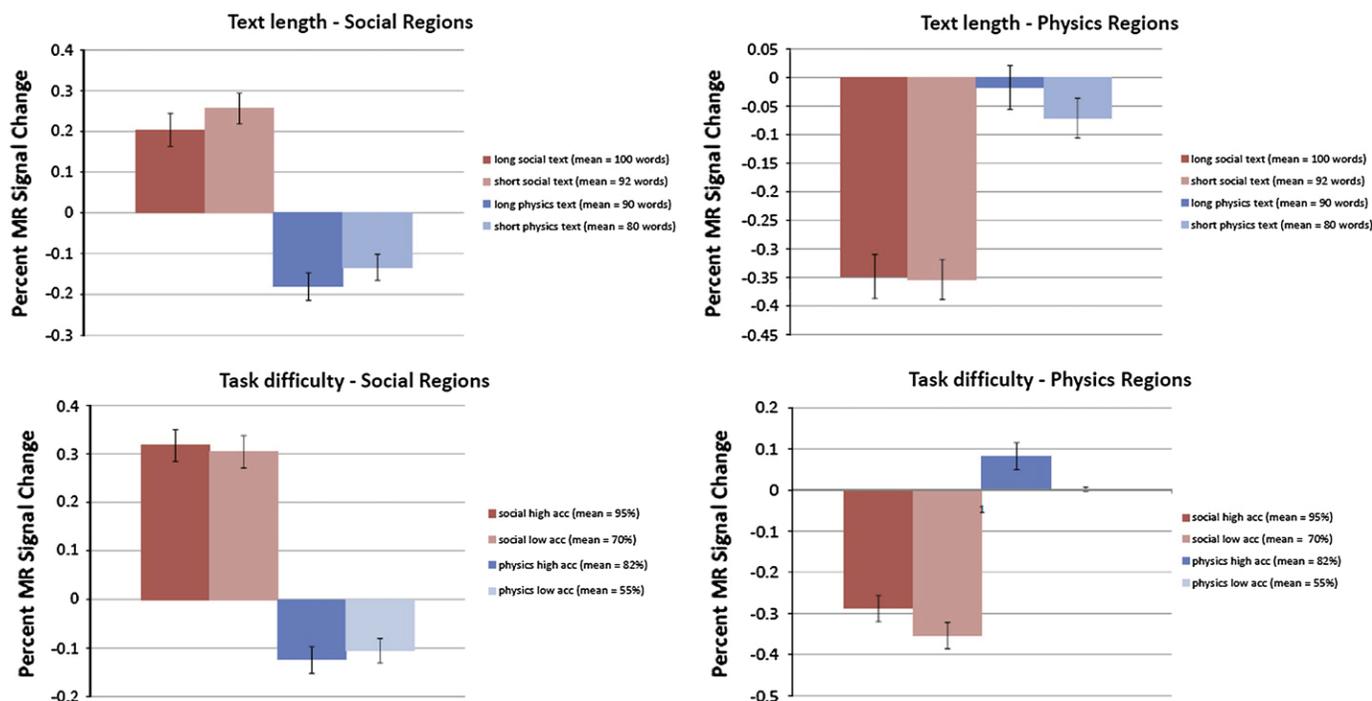


Fig. 5. Influence of text length and task difficulty on average activity in the social and mechanical networks (defined by random effects strict conjunction). Voxelwise analyses failed to identify any significant differences in individual regions due to these potential confounds (see [Correspondence with resting state anti-correlations section](#)).

533 between the social and mechanical videos (number: social 2.4  
 534 mechanical 2.1  $t(37)=0.8$ , n.s.; time: social 5.9 s mechanical  
 535 6.1 s  $t(33)=1.1$ , n.s.). For the texts, we counted the number of  
 536 verbs that described actions. There were significantly more action  
 537 verbs in the social than the mechanical texts (all non-auxiliary  
 538 verbs: social texts 15.5 mechanical texts 10.4  $t(36)=6.9$ ,  $p<0.001$ ;  
 539 verbs describing a physical action involving the limbs performed by  
 540 a person: social texts 9.4 mechanical texts 3.1  $t(38)=8.0$ ,  $p<0.001$ ).  
 541 Thus, by any measure, the number of actions in the social conditions  
 542 was greater than or equal to the number of actions in the mechanical  
 543 conditions. Therefore, demands associated with action observation  
 544 drove activity in the opposite direction to the effect of domain, and  
 545 cannot account for the consistent preference of regions associated  
 546 with action observation for mechanical reasoning.

#### 547 Task difficulty

548 A third potential confound relates to task difficulty. Prior studies  
 549 have found that more difficult tasks are associated with greater activa-  
 550 tion of dorsal attention network and fronto-parietal control net-  
 551 work, and with greater deactivation of the default network (Mason  
 552 et al., 2007; McKiernan et al., 2003). Task difficulty cannot account  
 553 for the pattern seen in antagonistic areas, since rest is clearly less  
 554 difficult than any of the four tasks and hence an explanation of activity  
 555 in terms of task difficulty would require that all four conditions  
 556 are either above or below resting level. However, task difficulty  
 557 might account for other regions identified in the direct contrast be-  
 558 tween social and mechanical tasks. The best proxy measure for task  
 559 difficulty is mean task accuracy. Mean accuracy was higher for the so-  
 560 cial conditions (mean=82%) than for the mechanical conditions  
 561 (mean=68%), consistent with the possibility that task difficulty  
 562 might be confounding the contrast between domains. First, we  
 563 performed a median split on the items in each condition. The median  
 564 split produced conditions with a mean difference of 26% in accuracy,  
 565 greater than the 14% mean difference in accuracy between the overall  
 566 social and mechanical conditions. We then performed a voxelwise  
 567 contrast comparing difficult questions to less difficult questions i.e.  
 568 (more difficult social+more difficult mechanical)–(less difficult

social+less difficult mechanical). When this analysis was done 569  
 using the same method of strict conjunction employed for the main 570  
 analyses, no areas passed multiple comparison correction. Hence, 571  
 task difficult by itself cannot account for any of the regions identified 572  
 in the contrast between domains. Might it have contributed to some 573  
 regions? To examine this, we reversed the confound by contrasting 574  
 the easier half of the mechanical conditions (mean=82%) with the 575  
 harder half of the social conditions (mean=70%), as shown in 576  
 Fig. 5. In social regions, the difference between conditions remained 577  
 the same. In mechanical regions, we saw a significantly greater differ- 578  
 ence between conditions. Since an even greater differentiation was 579  
 found between mechanical and social conditions when the contrast 580  
 involved mechanical conditions that were easier than the social con- 581  
 ditions, task difficulty can be ruled out as a confound. 582

#### 583 Working memory and episodic memory

584 A fourth pair of potential confounds relates to mnemonic de- 585  
 mands. A preference for mechanical cognition was observed in parts 586  
 of the middle frontal gyrus associated with working memory (Owen 587  
 et al., 2005). Conversely, a preference for social cognition was 588  
 observed in medial parietal / posterior cingulate and medial prefrontal 589  
 areas associated with episodic retrieval (Buckner and Carroll, 2007). 590  
 This raises the concern that differences in episodic and working 591  
 memory demands might account for the observed difference between 592  
 domains. These demands are not easy to quantify, however three con- 593  
 siderations suggest the differences in activity could not be accounted 594  
 for by low-level differences in mnemonic demands. First, there was 595  
 no episodic retrieval or future imagining demands associated with 596  
 the tasks. Each stimulus in each condition was self-contained, making 597  
 no reference to other stimuli, or to private or to public events that 598  
 participants might be able to recall. Second, with regard to working 599  
 memory demands, both the social and the mechanical conditions 600  
 contained numerous details that needed to be held in mind in order 601  
 to make sense of the narrative. Further, given that the social texts 602  
 were an average of 11 words longer than the physics texts, the work- 603  
 ing memory demands would be expected to be higher in the social 604

gyrus, medial parietal and medial prefrontal) were activated well above baseline for tasks in one domain, and suppressed well below baseline levels during tasks from the other domain (Figs. 3, A–C). If the contrast between domains were driven by differences in episodic and/or working memory demands, then these demands would have to be greater than those associated with resting fixation for one set of tasks, and less than those associated with resting fixation in the other set of tasks. The existence of differences in mnemonic demands that fits this pattern does not appear plausible. Therefore, it is unlikely that mnemonic demands are driving the differences between domains.

#### Response related confounds

A fifth pair of potential confounds concerned the valence of correct response (i.e. whether the correct response was yes or no), and accuracy (whether response given was correct or not). These were examined using contrasts that were statistically equivalent to the tests used in the main analysis. For instance, to examine the effect of valence of correct response, the contrast (social movie correct response yes + mechanical movie correct response yes)–(social movie correct response no + mechanical movie correct response no) was combined using strict conjunction with the identical contrast for text conditions. Neither potential confound yielded any brain regions which passed multiple comparison correction. In addition, we examined the influence of both factors on averaged activity across the entire social network and the entire mechanical network (as identified using random effects strict conjunction). These can be seen in Fig. 6. It is clear from both these analyses that neither of the potential confounds examined could account for the pattern of results obtained.

#### Discussion

We identified social and mechanical reasoning tasks which produced a pattern of reciprocal activation and suppression in two brain networks. Each of the four tasks produced activation in one network, and deactivation in the other network. Hence, each task recruited processes that were excitatory with respect to one network, and suppressive with respect to the other. These antagonistic areas corresponded very closely to regions of maximal anti-correlation generated using

resting connectivity, indicating their correspondence with previously described TPN and DMN networks.

Might these findings also be explained by other hypotheses? A number of researchers have characterized the DMN as a network specialized for internal attention (attention to self and/or internal states), which is opposed by a network specialized for external attention (Buckner and Carroll, 2007; Goldberg et al., 2006; Gusnard, 2001). While there may be competition between internal and external attention, this cannot account for the current findings. All of the tasks used here were externally focused: Each demanded perceptual attention and involved people and objects unfamiliar to the participants. There were no explicit demands to engage in hypothesized forms of internal attention, such as episodic memory, future thinking or self-referential cognition. In addition, the perceptual attention demands were higher for the social than the mechanical texts, which should produce the pattern opposite to that observed. While explicit task demands cannot account for our findings, it might be argued there are implicit demands to engage in internal attention that differentiate the tasks (Buckner and Carroll, 2007). If present, such implicit demands might account for regions revealed by the contrast between domains (but see additional analyses which cover some potential confounds). However, we do not know of any well-articulated notion of ‘internal’ or ‘self-referential’ cognition that might account for the differences relative to rest observed in antagonistic areas. The motivation for associating the default mode network with internal or self-referential cognition derives from the idea that this network is maximally activated when participants are at rest, a state in which the participant is effectively deprived of any external stimulus and hence must internally generate their thoughts. However, in our data, the antagonistic areas in the DMN were considerably more active when participants were attending to external stimuli, than at rest. Hence, the pertinent distinction which distinguishes which network is activated, and which network is deactivated, is between two types of externally directed attention: one in which the focus is on social interaction and the mental states of others, and another in which the focus is on inanimate objects and the physical principles that determine their mechanical interactions.

The spatial location of the antagonistic areas also argues against the external vs. internal attention hypothesis as an account of the tension between the TPN and DMN. First, the antagonistic regions in the

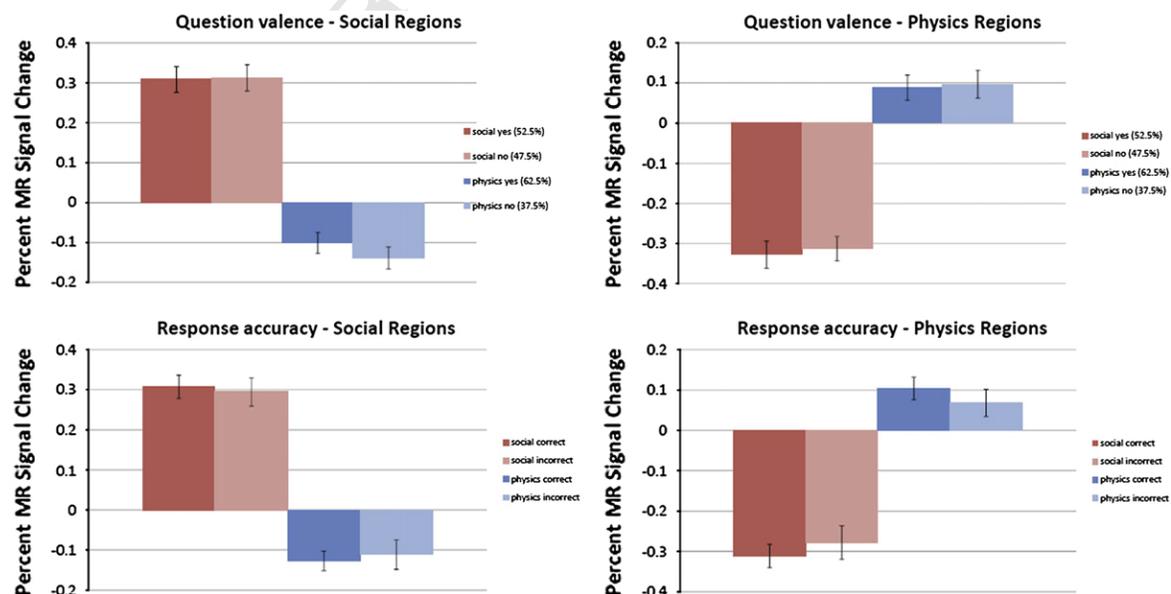
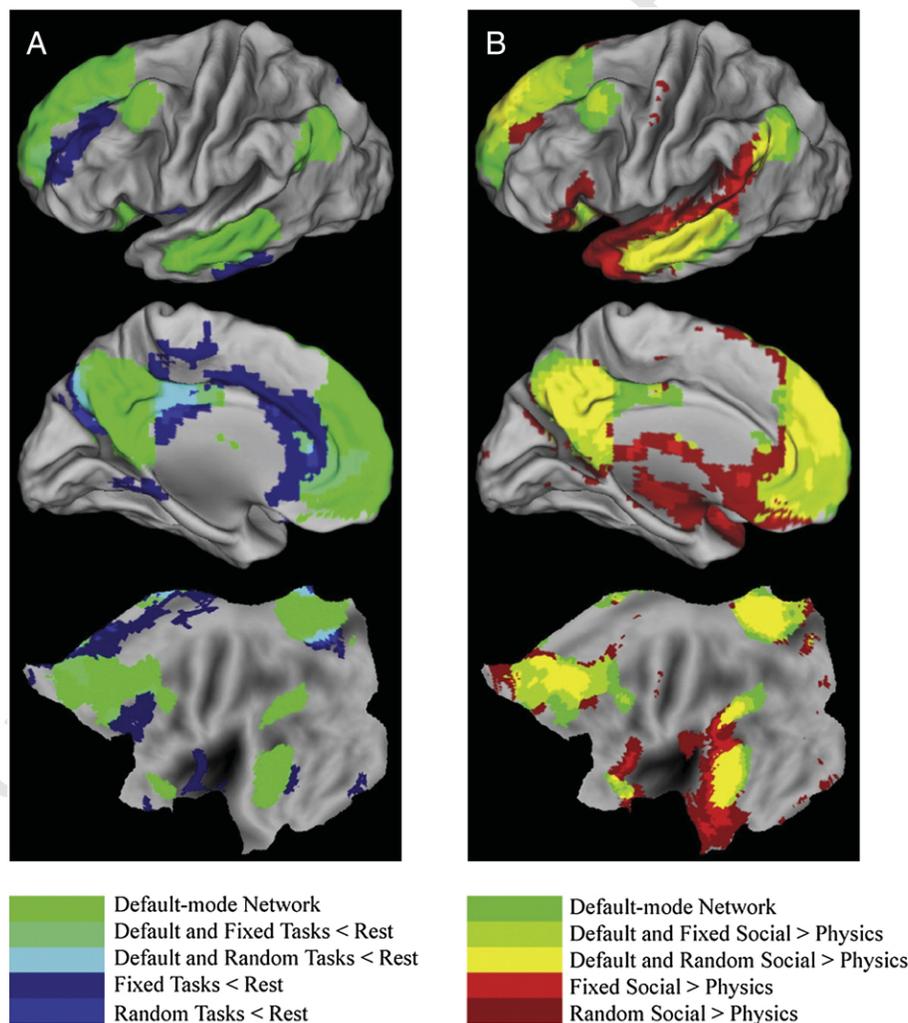


Fig. 6. Influence of question valence (correct answer yes or no) and response accuracy on average activity in the social and mechanical networks (defined by random effects strict conjunction). Voxelwise analyses failed to identify any significant differences in individual regions due to these potential confounds (see Correspondence with resting state anti-correlations section).

TPN are distinct from regions that are most clearly associated with visual attention, i.e., frontal and parietal regions containing retinotopic maps (Jack et al., 2007). Second, the antagonistic regions in the DMN are distinct from regions involved in episodic memory (Spaniol et al., 2009), and the region in DMPFC is clearly dorsal to the region involved in self-oriented cognition (Mitchell et al., 2006). A recent meta-analysis of 107 neuroimaging studies found a preference for other- over self-related judgments in each of the social antagonistic areas identified here (dMPFC, MPC, rTPJ) (Denny et al., 2012). Finally, areas of maximal anti-correlation, the phenomenon which originally defined the TPN vs. DMN dichotomy, corresponded very closely with the antagonistic areas identified here, and did not correspond well with areas that would be predicted by the internal vs. external attention hypothesis. This provides compelling evidence for the opposing domains hypothesis over the internal vs. external attention hypothesis. Nonetheless, our findings do not rule out the possibility that there is a tension between external and internal attention. Fig. 7A illustrates regions that were more active during rest than any of the tasks used here, and hence which may be associated with internal attention and/or spontaneous cognition. Further work may identify distinct processes that excite and inhibit other parts of those networks. On the other hand, it does appear that the contrast between the cognitive modes our tasks recruit accounts for much of the default network, illustrated in Fig. 7B.

Numerous studies have demonstrated that DMN regions are involved in a broad range of social, emotional and moral cognitive processes. A number of comprehensive reviews and meta-analyses cover this work (Amodio and Frith, 2006; Mars et al., 2012; Schilbach et al., 2008; Van Overwalle, 2009). Many of the best regarded of these studies employed rigorously controlled experimental designs aimed at isolating specific social functions. Yet, with regard to the tension between the DMN and TPN, these studies may have missed the wood for the trees. Our study was designed to be specific in a different way: by recruiting processes from just one domain. Thus, for example, our social tasks involved a range of socio-emotional processes, including theory of mind, emotion recognition and moral cognition, yet we strove to minimize the degree to which these tasks involved the sorts of analytic reasoning, mental manipulation, and/or deliberately controlled attention that are often demanded by carefully controlled behavioral designs. Ultimately, the proof of our success lies in the data. We were able to show clear activation of DMN regions accompanied by clear deactivation of TPN regions, and vice-versa. This suggests that, while the tasks used here no doubt recruited a broad range of processes, they nonetheless successfully separated out cognitive processes preferentially associated with the DMN and TPN. In contrast, prior investigations appear to have engaged processes associated with both cognitive modes, and hence recruited regions in the TPN alongside the DMN (Meyer et al., 2012; Spreng et al., 2010).



**Fig. 7.** Comparison of default-mode regions associated with internal attention and/or spontaneous cognition, and default-mode regions associated with the division between social vs mechanical reasoning. The default-mode network is shown in green. (A) Regions that are more active during rest than any of the four tasks used here are shown in blue. Overlap between default-mode network and consistently deactivated areas shown in light green and blue. (B) Regions preferring Social to mechanical reasoning are shown in red. Overlap with default-mode network shown in yellow / light green. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The mechanism by which the TPN and DMN suppress each other remains to be determined. Anatomical studies suggest that there are no direct inhibitory links between these brain networks, hence it is likely that the suppression is mediated by other regions. Since the effect of domain was consistent across two modalities of presentation (text and video), and the perceptual demands were similar for the social and physical tasks within each modality, it appears that the mechanism is distinct from mechanisms of perceptual attention. One possibility, suggested by (Spreng, 2012), is that regions in the FPCN mediate the relationship between the TPN and DMN. This is consistent with the observation that some regions in the FPCN were activated during both social and non-social tasks in the current investigation.

Why are DMN and TPN regions co-activated in some studies? It appears that, while there is a tendency for one network to be suppressed when the other is active, this tendency can be overridden by additional task demands e.g. where information from the DMN needs to be communicated to FPCN regions involved in planning (Spreng et al., 2010), or where information held in the DMN needs to be manipulated to perform a complex working memory task (Meyer et al., 2012). A further unanticipated clue concerning the relationship between the networks derives from the time course of BOLD activity seen in opposing areas. Notably, there is a clear pattern of activation and deactivation which persists throughout the stimulus presentation period (Figs. 3, A–F). However, this pattern is disrupted during the question/response period. During this time period, we observe a pattern which is closer to what has typically been observed i.e. the TPN is not deactivated (Figs. 3, A–C), even for conditions which activate the DMN (Figs. 3, D–F). Hence it would appear that the decision making and response related processing which occurs during this period is sufficient to drive up activity in the TPN even when the task involves social-emotional processing. The co-activation of DMN and TPN regions during this period may reflect the communication of information represented in the DMN to areas involved in decision making and response. Mutual suppression is seen when the only task required of participants is to use perceptual information to build a representation. This suggests that the information processing resources which build representations used in social and mechanical reasoning are (at least in part) mutually incompatible.<sup>3</sup> Hence these findings suggest a limit to our capacity to form concurrent representations that span these domains. This is consistent with prior work which shows that entraining participants in an analytic cognitive set, by giving them mathematical problems, suppresses empathetic response (as measured by charitable donations) when a picture and story of a distressed individual is subsequently presented (Small et al., 2007). These findings also suggest a mechanism that may account for syndromes in which dysfunction in one domain is accompanied by cognitive strength in the other. Most notably, individuals with autism perform better than IQ matched controls on scientific reasoning (Baroncohen et al., 1986), spatial fluid intelligence tasks (Dawson et al., 2007; Hayashi et al., 2008), and some attention tasks (Baron-Cohen, 1998; O’Riordan et al., 2001). A number of individuals with autism also show extra-ordinary visual creativity. Fronto-temporal dementia is associated with declining social function, and some patients also display an increase in visual creativity as the disease progresses (Miller and Hou, 2004). The converse pattern appears in Williams syndrome, which is characterized by high levels of empathy but impaired visual-spatial ability (Brown et al., 2003). Further work is needed to determine how variability in human performance relates to the present biological observations.

These findings indicate that cognitive context, i.e., the primary cognitive mode that is engaged by a task, has a surprisingly powerful effect

<sup>3</sup> In contrast, we suggest the co-activation of these networks at the time of response suggests it is possible for processes associated with either network to operate on representations stored in the DMN and TPN (social and mechanical representations, respectively).

on the recruitment of brain areas. A number of brain areas showed patterns of activation that do not fit easily with widely held notions of their cognitive function. For instance, much of the ‘dorsal attention system’ (Corbetta and Shulman, 2002; Fox et al., 2006) was suppressed below resting levels during the social tasks, although these tasks clearly involved greater perceptual demands than resting fixation. Similarly, lateral frontal areas associated with working memory (Owen et al., 2005) showed radically different patterns of deactivation and activation in the social and mechanical reasoning tasks, although all the tasks required participants to maintain numerous details in working memory. Several researchers have drawn a close analogy between folk psychology and folk physics (Gopnik, 1996; Lewis, 1972; Saxe, 2005) because they both involve similar high-level psychological processes such as abstraction, inference, model building, prediction, and the postulation of unobservable processes or states. However, the present observations are difficult to reconcile with a view of functional organization which is driven by these apparent similarities: The degree to which different brain areas are recruited cannot be explained simply on the basis of the psychological processes that are required to perform a given task. These findings suggest a model of functional organization in which cognitive domain also plays a major role in determining how brain areas are recruited. It appears that there are fundamental differences in the information processing resources that are recruited, depending on the primary cognitive mode engaged by the task context. A similar finding has been demonstrated by studies using the Wason selection task, which show that the computational resources recruited depend on whether the task is framed as a social or mechanical problem (Cosmides, 1989; Fiddick et al., 2000). This and related work (e.g. on the representativeness heuristic (Kahneman and Tversky, 1972)) has helped spur dual-process theories of cognition which distinguish between System 1 and System 2 reasoning systems (Evans, 2003; Kahneman, 2003; Sloman, 1996). System 1 has been variously characterized as ‘intuitive’, ‘emotion-driven’ and ‘experiential’; whereas System 2 has been characterized as ‘controlled’, ‘rule-based’, ‘rational’ and ‘analytic’. We know of two lines of work which link cognitive neuroscience to this classical form of dual process theory: one which looks at logical reasoning (Goel and Dolan, 2003), the other moral judgments (Greene et al., 2004). Both identify areas in the DMN and TPN associated with System 1 and System 2 reasoning respectively. Hence, the link between dual-process theories of cognition and the DMN vs. TPN dichotomy appears worthy of further investigation.

A novel type of dual processing account has recently been proposed to account for disparities in performance on explicit and implicit measures of theory of mind. According to one version of this account, implicit measures reflect the operation of an inflexible and automatic implicit system, whereas explicit measures reflect the operation of a more flexible but cognitively demanding explicit system (Aperly and Butterfill, 2009). We reject this account for a variety of reasons. First, it has been shown that the information processing reflected by implicit measures of theory of mind is not wholly automatic because it is prone to dual-task interference (Schneider et al., 2012). Concordant with this, the pattern of reciprocal inhibition between the TPN and DMN provides compelling evidence that the DMN is involved in controlled processing—if it were wholly automatic and its processing can proceed in parallel, then deactivation of the DMN would not be such a reliable function of non-social cognitive load (Gordon et al., 2007; Mason et al., 2007; McKiernan et al., 2003). Closing the loop, recent evidence shows that DMN activity associated with mentalizing is diminished by a concurrent dual task (Spunt and Lieberman, in press). Third, it does not appear accurate to describe the mentalizing system of the DMN as implicit in the sense of being unconscious, since this system is implicated in more cognitive representational aspects of emotion processing (Kober et al., 2008; Shamay-Tsoory et al., 2009; Zaki and Ochsner, 2011) and is reliably engaged during introspection, i.e. when we consciously represent our internal states (Schilbach et al., 2012).

Rather than postulate two distinct systems whose operation is reflected by implicit and explicit measures of theory of mind, our theory postulates two distinct cognitive modes for mentalizing which both recruit the DMN but differ in terms of how they recruit the TPN (Fig. 8). Implicit measures are thought to reflect the adoption of the Phenomenal stance, the 'default mode' of social cognition which is emotionally engaged and focused on the representation of experiential states. This stance is hypothesized to engage the DMN and deactivate the TPN. Explicit measures are thought to recruit a different mode, the Intentional stance, an emotionally disengaged form of social cognition in which processes associated with the TPN are recruited in order to manipulate and transform representations of internal mental states (held in the DMN) so that they can guide response. This is consistent with evidence suggesting that explicit theory of mind measures depend on additional non-social cognitive processes (Bloom and German, 2000), specifically executive functions such as inhibitory control (Carlson and Moses, 2001). The Intentional stance is thought to be engaged not just by explicit theory of mind tasks and tasks requiring mental manipulation of social representations (Meyer et al., 2012), but also in naturalistic settings when individuals are engaged in competitive or 'manipulative' (anti-) social interactions. This is consistent with meta-analytic findings which show tasks involving deception reliably recruit regions in the TPN associated with executive functions (Christ et al., 2009).

Why is there an antagonism between brain areas involved in social and mechanical reasoning? This may seem surprising, given that the instantiation of these functions in different brain regions might facilitate their occurring simultaneously without interference. One possibility is that incompatible heuristics are most effective for predicting the behavior of persons versus inanimate objects. It would be no less foolish to suppose that a person will continue in motion in a straight line unless acted upon by an external force, than it would be to suppose that a pool ball will alter its course because it wants to go into the pocket. Experimental evidence demonstrates that we have an automatic tendency to track the mental states of others, and that this can interfere with performance on an unrelated task (Samson et al., 2010). Hence, turning off the brain areas for the opposing domain may lessen the application of inappropriate cognitive strategies. However, our view is slightly different. We do not see the principle function of the cognitive mode which

suppresses the TPN as the prediction of behavior, but as generating a distinctly social form of interpersonal understanding ('intersubjectivity'). According to our model (Fig. 8) and supporting behavioral work (Jack and Robbins, 2012) there is a tight linkage between thinking about experiential mental states and moral concern. Consistent with this, moral cognition produces an activation pattern that closely fits the default network (Harrison et al., 2008). Our hypothesis is that the inhibition between domains is driven by the need to differentiate members of our moral circle from objects suitable for manipulation. In terms of effective strategies, it would be a mistake to limit the actions one is willing to perform on an inanimate object out of a sense of compassion. In contrast, it is often advisable to demonstrate sensitivity to an in-group member's feelings when interacting with them. Hence, our view is that the antagonism between domains reflects a powerful human tendency to differentiate between conscious persons and inanimate objects in both our attitudes and modes of interaction.

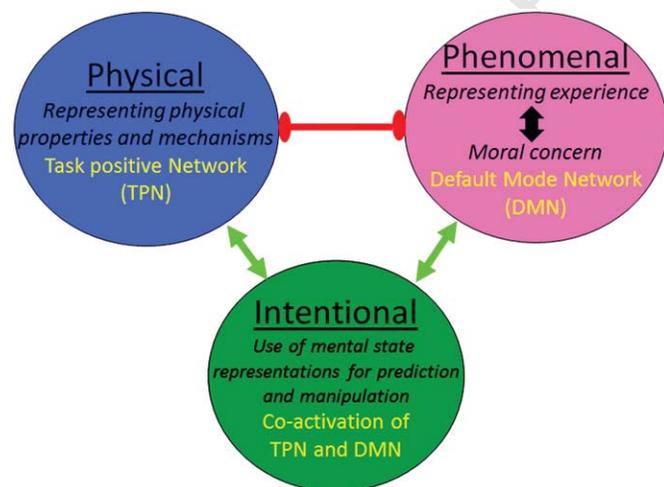
### Limitations

The most significant limitation of the current study is that our tasks were not designed to isolate specific cognitive processes involved in social (or mechanical) cognition. Hence, while the social and mechanical tasks used were successful in separating out processes associated with the DMN and TPN respectively, this study does not allow us to identify which of a number of the potential candidate processes associated with the social and mechanical tasks might be responsible for suppressing the opposing network. A second limitation is that our ecologically valid tasks did not afford an opportunity to parametrically vary processing load. Parametric variations in cognitive load would provide an additional method for identifying key processes responsible for deactivation of the TPN, as they have done in studies investigating deactivation of the DMN (Gordon et al., 2007; Mason et al., 2007; McKiernan et al., 2003). It is possible that future investigations may be able to pinpoint a single isolated cognitive process which leads to deactivation in the TPN. Alternatively, it may be that this deactivation only occurs when a range of different socio-emotional processes are simultaneously recruited. If the suppression of the TPN mirrors the pattern seen for the DMN, then it is likely that a family of different processes are capable of producing deactivation, and that the degree of suppression of the TPN increases with increasing recruitment of any of this family of processes.

A third limitation concerns the ability of the current study to accurately characterize the extension of the family of processes that deactivate the TPN. No single study can adequately address this issue, and it is possible that the characterization of the processes that suppress the TPN will be prone to the same process of revision which has marked the history of attempts to correctly characterize the family of processes which deactivate the DMN. All that we can definitely state on the basis of this investigation is that the social cognition tasks used here did reliably recruit processes which suppressed the TPN, even though attention was directed externally rather than internally. On the other hand, we note that all the tasks we know of which have been shown to recruit the DMN above resting levels have clearly involved social cognition (Iacoboni, 2004; Meyer et al., 2012; Sestieri et al., 2010; Spreng et al., 2010). Following the theoretical work which motivated this investigation (Jack and Robbins, 2012; Robbins and Jack, 2006), we hypothesize that any task that involves thinking about experiential mental states will both activate the DMN and cause suppression of the TPN.

### Acknowledgments

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**Fig. 8.** Three cognitive stances, their relationships to each other, and the brain networks involved. Bidirectional arrows indicate mutual compatibility; barbell indicates mutual antagonism. The Intentional stance is a distinct cognitive mode in which processes associated with the task positive network operate on representations stored in the default network. Nonetheless, there remains a fundamental tension between cognitive modes involved in the representation of experiential mental states (the Phenomenal stance) and the representation of physical mechanisms (the Physical stance). The opposing domains hypothesis holds that this tension represents the cognitive basis of the reciprocal inhibition between default and task positive networks.

**Appendix A. Peak coordinates (foci) associated with random effects analyses. All z statistics are minima of the contrasts that are conjoined (i.e. minimum z from two contrasts for direct comparisons of social and mechanical, minimum of four contrasts for comparisons with rest). Spaces are reported in 711-2B space, a modified version of talairach.**

Conjunction	X	Y	Z	z-stat	Conjunction	X	Y	Z	z-stat
social > rest, mechanical < rest	-2	-56	31	4.9	mechanical > rest, social < rest	-52	-39	42	3.7
social > rest, mechanical < rest	-1	46	27	3.7	mechanical > rest, social < rest	-37	-46	39	3.6
social > mechanical	12	-96	18	3.0	mechanical > rest, social < rest	-39	32	19	3.4
social > mechanical	26	-77	-33	5.4	mechanical > social	39	-78	26	3.1
social > mechanical	-22	-73	-33	3.8	mechanical > social	-24	-69	41	4.8
social > mechanical	-52	-65	29	5.5	mechanical > social	33	-69	42	3.2
social > mechanical	-58	-59	19	4.6	mechanical > social	17	-67	48	5.9
social > mechanical	51	-57	26	6.5	mechanical > social	-12	-66	53	6.1
social > mechanical	2	-56	3	3.2	mechanical > social	35	-63	-37	4.9
social > mechanical	1	-55	30	8.7	mechanical > social	-52	-59	-6	7.0
social > mechanical	3	-50	-38	4.4	mechanical > social	57	-55	-10	5.7
social > mechanical	-6	-46	10	3.1	mechanical > social	-19	-49	47	3.3
social > mechanical	60	-44	10	5.4	mechanical > social	37	-46	-52	3.1
social > mechanical	6	-38	4	5.3	mechanical > social	-30	-44	-7	4.0
social > mechanical	-52	-38	0	6.2	mechanical > social	-45	-44	45	7.0
social > mechanical	-35	-32	19	3.0	mechanical > social	40	-43	46	7.3
social > mechanical	-9	-31	-5	4.1	mechanical > social	30	-42	-7	5.1
social > mechanical	17	-27	-7	4.7	mechanical > social	54	-37	43	7.5
social > mechanical	52	-27	-5	6.7	mechanical > social	14	-36	42	3.8
social > mechanical	-58	-26	-6	7.2	mechanical > social	-60	-34	37	6.1
social > mechanical	1	-22	40	5.6	mechanical > social	-13	-33	39	4.3
social > mechanical	-20	-18	-10	5.1	mechanical > social	-23	-15	51	3.8
social > mechanical	53	-16	-10	6.6	mechanical > social	-37	-10	4	5.5
social > mechanical	2	-16	11	4.8	mechanical > social	40	-7	4	4.6
social > mechanical	67	-13	-11	4.4	mechanical > social	-2	-3	32	5.6
social > mechanical	21	-12	-8	5.0	mechanical > social	-23	0	55	5.9
social > mechanical	-52	-6	-14	5.5	mechanical > social	23	0	54	4.2
social > mechanical	48	2	-22	6.5	mechanical > social	-48	1	27	5.8
social > mechanical	-48	4	-24	5.0	mechanical > social	48	2	21	5.7
social > mechanical	32	13	-12	5.2	mechanical > social	-29	13	7	3.5
social > mechanical	-36	13	-15	4.6	mechanical > social	-5	20	48	3.0
social > mechanical	37	14	-32	3.4	mechanical > social	-42	31	23	6.6
social > mechanical	3	17	66	3.0	mechanical > social	42	35	21	6.5
social > mechanical	2	17	-4	3.5	mechanical > social	-45	38	13	5.5
social > mechanical	53	20	15	4.0	mechanical > social	41	47	7	3.3
social > mechanical	49	22	4	4.1					
social > mechanical	-44	24	-2	3.9					
social > mechanical	17	30	43	3.0					
social > mechanical	13	34	55	3.7					
social > mechanical	2	40	-11	4.6					
social > mechanical	-2	48	23	7.1					
social > mechanical	18	48	41	3.6					
social > mechanical	4	48	44	5.6					
social > mechanical	-15	52	33	4.0					

## Appendix B. text stimuli

### Physics Stories

A guitar is a musical instrument with five metal strings of varying thicknesses. Plucking the strings causes them to vibrate and produce a sound. Each string has a different pitch depending on its thickness, which affects the speed of the vibration. The lightest or thinnest string will vibrate the quickest, while the heaviest string will vibrate the slowest. To test the pitch, the lightest string is plucked.

Will the lightest string that vibrates fastest produce the lowest pitch?

A block of solid lead is placed on a scale in the elevator of a building on campus. The elevator is taken to the top floor, and when the elevator doors open and the scale stops moving, the weight of the solid lead block is recorded. Now, the button for the basement is pressed, the doors of the elevator close, and the elevator moves downward. As it starts to move, the lead block's weight changes.

According to the scale, does the weight of the lead block decrease?

On a hot, sunny day, two metal buckets sit in direct sunlight. The buckets are the same size, but one is dark black while the other bucket is painted shiny silver. In the morning, the temperatures are the

same. As the sun heats up the buckets throughout the day, the black bucket heats up faster than the shiny bucket. That night, the air temperature drops and the buckets begin to cool at different rates.

Will the black bucket cool more quickly?

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?

A rifle is being tested at a long, flat firing range. The gun is propped up on a table, with a few bullets sitting on the table next to the gun. After looking down the firing range to insure that nothing is in the way, the trigger is pulled, firing the gun perfectly straight. At the same instant that the trigger is pulled, a bullet rolls off the table and falls to the ground. The two bullets eventually hit the ground.

Will the bullets hit the ground at the same time?

A membrane separates a tank into two equal halves. The membrane allows water molecules to pass through, but not large molecules such as red dye. The tank is filled almost to the brim with

958	water. Then concentrated red dye is poured into one of the sides until	
959	that side reaches the brim, changing its concentration. The dye causes	
960	water from the other side to pass through the membrane to the red	
961	side. The red side begins to overflow.	
962	Will the clear side without dye empty completely?	
963	To test the effects of buoyancy, a heavy rock has been placed into a	
964	boat that is floating in a small pool filled to the brim with water. The	
965	rock is then taken out of the boat, and the water level decreases. Fi-	
966	nally, the rock is put into the water, and it sinks to the bottom of	
967	the pool. The water level increases.	
968	Will the pool overflow?	
969	There is a basket on a conveyor belt connecting two sides of a can-	
970	yon. The basket carries materials from one side to the other. When	
971	the basket successfully reaches one of the sides it stops and the bot-	
972	tom of the basket opens, releasing its contents onto a platform. One	
973	day when the basket is in the process of moving across the canyon,	
974	the bottom of the basket breaks opens and its contents fall into the	
975	canyon.	
976	Will the objects fall straight down when they are released?	
977	A roller coaster uses electromagnets to accelerate to high speeds.	
978	It is designed so that it travels along a flat portion before heading	
979	straight up an incline. The car starts at rest and then accelerates,	
980	reaching top speed as it begins to climb the hill. As it climbs, gravity	
981	pulls on the car, causing it to slow down and eventually stop. It begins	
982	to fall back down the hill, gaining speed as it goes. The car reaches the	
983	bottom of the hill.	
984	Will the car continue to accelerate?	
985	Two cannonballs are brought to the top of a tower. Both are placed	
986	on a platform over the edge of the tower. When a button is pressed	
987	two things will occur simultaneously. A platform underneath one	
988	ball will drop, releasing the ball and allowing it to fall straight	
989	down. Also, a powerful spring behind the second ball will push it hor-	
990	izontally away from the tower and parallel to the ground. Eventually,	
991	both balls reach the ground.	
992	Will the two balls hit the ground at the same time?	
993	As a train approaches a bridge, it sounds its horn continuously to	
994	warn those ahead. The whistle's pitch sounds relatively high and con-	
995	stant to an observer standing on the bridge as the train approaches.	
996	When the train goes under the bridge, the pitch changes to a lower	
997	pitch, and stays constant as it travels farther from the bridge. Then,	
998	the train starts to slow down as it nears its station, and the whistle's	
999	pitch changes.	
1000	Does the pitch get higher as the train slows down?	
1001	A large rectangular block of wood sits on an ice rink and needs to	
1002	be removed. A rope is tied around the block and workers pull the	
1003	block of wood over the ice and off the rink. Due to the ice rink's	
1004	setup, the block can be pulled straight off the ice rink and over a con-	
1005	crete floor. While it takes a great amount of pulling to get the ice	
1006	started moving, once in motion it is relatively easy to pull. Then the	
1007	workers reach the concrete.	
1008	Will it be easier to drag the block over the concrete floor?	
1009	A cannonball and volleyball are brought to the top of the tallest	
1010	building in the world. The balls are placed on a platform over the	
1011	edge of the building. This platform is built in such a way that when	
1012	a lever is pulled the balls are released at the exact same moment.	
1013	The lever is released, and the cannonball and volleyball accelerate to-	
1014	wards the ground. Due to air resistance, the volleyball eventually	
1015	stops accelerating.	
1016	Will the two balls hit the ground with the same speed?	
1017	A communications satellite is moving in stable orbit around the	
1018	Earth. The electrical panel on the satellite has a serious malfunction.	
1019	The speed of the satellite begins to gradually decrease, eventually	
1020	reaching half the original speed. A shuttle is sent up to repair the sat-	
1021	ellite, but before they can rendezvous the satellite begins to move out	
1022	of its stable orbit due to its decreased speed.	
1023	Will the satellite fall to earth due to its decreased speed?	
	A concave mirror can be used to ignite a match with a hot light. A	1024
	match is placed in the focal point of the mirror, so that any light that	1025
	hits the mirror will be focused directly onto the match. A bright light	1026
	is placed a few feet away from the mirror and turned on. Within a few	1027
	moments the match bursts into flames. A new setup uses the same	1028
	type of light and match, but uses a regular, flat mirror to reflect the light.	1029
	Will the regular mirror ignite the match?	1030
	A giant rock is put into a large bin and weighed. Then, a robotic	1031
	arm picks up the rock and places it into a machine that smashes up	1032
	the rock into smaller pieces so that the rock can be processed. After	1033
	this machine breaks the rock into thousands of tiny pieces they are	1034
	all collected and put back into the bin. This bin with all the tiny pieces	1035
	of rock is weighed to ensure that no rock was lost in the process.	1036
	Will the rock weigh the same as before?	1037
	Scientists want to design a rocket to reach space with the greatest	1038
	speed. They have created an experiment to test which of two possible	1039
	designs will work best. Two identical rockets have been set to launch	1040
	into outer space. One rocket is being launched in the same direction	1041
	as Earth's spin, while the other is being launched in the opposite di-	1042
	rection of Earth's spin. When they reach space, the two rockets are	1043
	going different speeds.	1044
	Will the rocket launched in the same direction as Earth's spin	1045
	reach a higher speed?	1046
	Two identical rectangular magnets are resting near each other on	1047
	a flat table. These magnets are identical in shape, size, and magnetic	1048
	strength. One end of each of the magnets is blue and the other is	1049
	red. The magnets are picked up and the blue ends are brought togeth-	1050
	er. The closer that the blue ends are brought together, the stronger	1051
	the magnets seem to repel away from each other. Then, the red	1052
	ends are brought together.	1053
	Will the red ends of the magnets repel one another?	1054
	Two commercial jet airplanes are flying from Cleveland to Boston.	1055
	The planes are identical in almost every way, except that one plane	1056
	has clearance to fly faster. On their approach into the airport, each	1057
	plane must make a turn in order to line up with a runway. The faster	1058
	plane makes the turn at a considerably faster speed than the slower	1059
	plane. One of the planes is able to turn more sharply.	1060
	Will the faster plane turn less sharply?	1061
	A paper cup is placed directly above a flame from a Bunsen burner	1062
	that is turned on high. Within a few moments the cup bursts into	1063
	flames. Then, an identical cup is filled with water and placed the	1064
	same distance from the Bunsen burner's flame. After a few moments,	1065
	the water filled cup does not catch fire. A few minutes passes with the	1066
	cup directly in the heat. The water temperature increases and it be-	1067
	gins to boil away.	1068
	If the water boils away completely, will the cup burst into flames?	1069
	Physics stimuli summary	1070
	1554 words	1071
	14.1 words/sentence	1072
	2.8 sentences/paragraph	1073
	Grade level 6.0	1074
	Reading ease 77.0	1075
	Social stories	1076
	Justin is afraid to tell his father that he didn't make the basketball	1077
	team during tryouts. His father is proud of Justin's older brother who	1078
	is a basketball star. Justin wants to please his father, but he's too clumsy	1079
	to be good at basketball. Ashamed to tell his father the truth, he comes	1080
	home late after school so his father thinks he was at practice. At the	1081
	hardware store, Justin's father happens to see the team coach and learns	1082
	the truth. He quietly stares down at the ground.	1083
	Will Justin's father come home feeling guilty?	1084
	James and Lauren plan on meeting for dinner to celebrate Lauren's	1085
	new job. James is determined to show up because he wants Lauren to	1086
	feel that he supports her career. Last time he had to cancel to	1087

- 1088 volunteer at Habitat for Humanity, but this time he promises to show  
1089 up. During the day James' dog gets hit by a car and needs to be rushed  
1090 to the vet. He tries to call Lauren but her cell phone has run out of  
1091 battery.
- 1092 Will Lauren think that James cares about her career?
- 1093 David worked all summer mowing lawns to save up for a new  
1094 video game. He buys the game, but he has to mow the neighbor's  
1095 yard before he can play it. He carefully puts the game in the middle  
1096 of his desk. David's younger sister Hailey is bored without a summer  
1097 job, so she sneaks into David's room and plays the game all afternoon.  
1098 She does not want David to know she played the game, but she mis-  
1099 takenly puts it on his dresser instead of the desk where he left it.
- 1100 Does David trust his sister?
- 1101 Sally invited Ann over to see the new doll that she got for her  
1102 birthday. While they are playing in her bedroom, Sally's mother  
1103 comes in looking angry and asks her to step outside to talk. Before  
1104 she leaves the room, Sally takes her new doll and puts it in her toy  
1105 chest. Ann decides to play a trick on Sally while she is gone. She  
1106 takes the doll out of the toy chest and hides it under the bed. She  
1107 then goes back to innocently playing on Sally's bed.
- 1108 When Sally gets back to her room, will she look for the doll under  
1109 her bed?
- 1110 George is in a fishing competition. Last year he placed first because  
1111 he cheated, pretending that he caught a fish that he actually pur-  
1112 chased. This year a camera crew is following him to witness his  
1113 catch. He nervously explains his techniques to the camera, praying  
1114 to himself that he gets lucky and catches a fish. Suddenly, his pole  
1115 bends over, and he screams with delight as he begins to reel in his  
1116 line. In actuality, George's lure is stuck on a small tire.
- 1117 Does George care what other people think of him?
- 1118 In preparation for her first high school dance, Sarah purchases a  
1119 revealing red dress and high heels. To afford the dress, she steals  
1120 money from her step-father's wallet. She doesn't feel guilty because  
1121 it was his fault that her parents got divorced. When she gets home,  
1122 Sarah puts her dress and shoes on the chair in her room. While  
1123 she's away, her older sister borrows the shoes to look good for the  
1124 stepfather and then carelessly leaves the shoes in the basement.
- 1125 Does Sarah's sister think Sarah was wrong to steal?
- 1126 Shannon spent all weekend studying for an exam, even though  
1127 Saturday was her father's birthday. Shannon decided that she must  
1128 study, because if she did well she could get into medical school. The  
1129 test went well, but Shannon feels guilty that she didn't spend more  
1130 time with her father. When Shannon gets her test back, she sees a  
1131 'D' written at the top of the paper, and in embarrassment quickly  
1132 puts it in her bag. She didn't notice that it is actually Jack's test. Her  
1133 real score is an 'A'.
- 1134 Does Shannon think that she received an A on the exam?
- 1135 Pam and Mike plan on having dinner to celebrate their anniversa-  
1136 ry. They have been fighting recently because Mike admits to fantasiz-  
1137 ing about Pam's twin sister. To make amends, he promises to make  
1138 dinner reservations at Pam's favorite restaurant. Pam looks forward  
1139 to the date, but Mike, dreading the dinner, waits until the last minute  
1140 to reserve a table. When he finally calls, the restaurant is booked. Re-  
1141 lieved, Mike reserves a table at his favorite restaurant, where Pam's  
1142 sister works.
- 1143 Does Pam think she is going to have fun at dinner?
- 1144 Rebecca and Patrick plan on going to see their favorite band. When  
1145 Rebecca calls to buy the tickets, they are all sold out. Worried that  
1146 Patrick will hate her for not getting tickets, she calls him in tears to  
1147 apologize. Patrick is not mad because he secretly bought the tickets  
1148 last week, but he wants to keep it a surprise so he doesn't tell her.  
1149 Rebecca feels bad about not getting tickets, so she buys him lunch,  
1150 which he gladly accepts.
- 1151 Is Patrick concerned about Rebecca's feelings?
- 1152 Elise has a puppy that she thinks is the cutest dog ever. Elise's  
1153 mother does not let her bring her new puppy into her room because  
he chews on everything. Because of this Elise always keeps her door  
closed. One evening as Elise is rushing to the bathroom, the dog  
slips into her room unnoticed. That night there is a loud thunder-  
storm and Elise awakens to hear strange growling and scratching  
under her bed. Elise runs screaming to her mother's bedroom.
- Does Elise think that her dog has turned nasty?
- Bill convinces Sue to purchase a season pass to an amusement  
park, but every time they have a chance to go it rains. Sue regrets get-  
ting the season passes, and complains to Bill all the time. In reality,  
she is relieved because she is afraid of roller coasters. This weekend  
the weather forecast predicts clear skies. Bill goes to sleep excited  
for the trip, while Sue dreads the upcoming good weather. While  
they sleep, the forecast changes to rain.
- Will Bill and Sue wake up thinking they are going to the amuse-  
ment park?
- Chris has developed a bad habit of skipping class to play online  
video games. He used to like going to class to see his friends, but lately  
he has been depressed and would rather just laze around in his room.  
Today he looks at his calendar and notices a test next week but noth-  
ing important today, so he skips class again. He was not in class last  
week to hear the teacher announce that the test has been moved up  
a week.
- Do Chris's friends care if he misses the test?
- Eric is an honors student, but he is having trouble keeping up with  
his challenging courses. He plans out his week so that he studies for  
exams, watches basketball with friends, and writes a history paper.  
He dreads writing the paper, so he puts it off to the last minute. He  
only checks out the library books for the project the day before the  
paper is due. While he's away, his mother sees the books and returns  
them, assuming he is finished with the project because it is due  
tomorrow.
- Does Eric's mother think that her son will be thankful?
- John and Mary are looking for their car keys. John is excited but  
nervous because he plans on proposing at dinner. Mary is stressed  
out because she just got fired at work but has not had the nerve to  
tell John. Both are looking for the keys frantically because they are al-  
ready late for their dinner reservation. Losing her temper, Mary  
storms outside to see if John left the keys in the car. While Mary is  
outside, John finds the keys between the couch cushions.
- Does John think Mary is upset about losing her job?
- Julia and her best friend Ashley have been fighting because Julia  
has been flirting with Ashley's boyfriend online. Julia regrets upset-  
ting her friend and decides to give her an ice cream cake when she  
comes over for a study date the next evening. Julia buys the ice  
cream cake and puts it in the freezer. That night, the power goes  
out and the ice cream cake melts into a gooey mess. When Ashley  
comes over, Julia tells her she has a special treat for her, and goes to  
open the freezer.
- Does Julia think that Ashley will be impressed?
- The Smith family went camping for the first time all together. Mr.  
Smith loves the outdoors, and he used to go camping every weekend  
with his ex-wife. Jessica, his new wife, hates camping but wants to  
impress her new husband. Jessica quickly becomes grumpy and  
then starts an argument around the campfire, and everyone goes to  
bed in a sour mood. A distracted Mr. Smith forgets to secure the  
food cooler, and that night a bear breaks into their cooler and eats  
all of the food.
- Does the bear want to ruin Mr. Smith's new marriage?
- Laura is preparing for a horse show, but has been distracted by a  
young man working at the stable. Every time he comes to clean out  
the horse stalls she blushes and runs away. This distraction has put  
her behind schedule, and the day of the competition she does not  
have time to braid her horse's mane. She cries on the way to school  
knowing she will not be able to compete that afternoon. During the  
day, the stable boy braids the horse's mane for Laura, hoping it will  
impress her.

- 1220 Does Laura know how the stable boy feels?  
 1221 Jenny has a horrible fight with her brother. He is always being  
 1222 cruel to her. She goes out to buy some ice cream to cheer herself up.  
 1223 Just as she gets home a friend calls and asks Jenny out to see a  
 1224 movie. Excited, she rushes out and carelessly leaves the ice cream  
 1225 on the table. Jenny's brother feels guilty. He sees the ice cream and  
 1226 puts it in the freezer. While she is watching the movie, Jenny sudden-  
 1227 ly remembers that she has left the ice cream out and feels sad again.  
 1228 Does Jenny think her brother is helping her out?  
 1229 Sue sneaks into the kitchen, gets on a chair, and puts her little  
 1230 hand into the candy jar to grab a heaping handful of treats. As she  
 1231 walks out of the kitchen, she smirks at the thought of disobeying  
 1232 her mother, who told her not to have any more sweets. But as she  
 1233 brings the candy to her mouth a sinking feeling of guilt comes over  
 1234 her. She knows the candy being saved for a party tomorrow. Conflict-  
 1235 ed, Sue finally decides to put the candy back and not eat any.  
 1236 Does Sue's mother think all of the candy is in the jar?  
 1237 Charlie is seen by his classmates as a nerd. He has been in love  
 1238 with Leah since fifth grade, but she is so popular he has never had  
 1239 the guts to tell her. He decides to hold a surprise birthday party for  
 1240 Leah. Charlie calls Leah's friends to invite them, but forgets to invite  
 1241 the most popular girl at school, Chloe. Jealous that she can't go,  
 1242 Chloe tells Leah about the party. Leah is touched that Charlie planned  
 1243 the party, so she decides to act surprised at the party anyways.  
 1244 Will Charlie think that he has surprised Leah?  
 1245 Social stimuli summary
- 1246 1915 words  
 1247 14.6 words/sentence  
 1248 3.2 sentences/paragraph  
 1249 Grade level 6.0  
 1250 Reading ease 77.8
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