Probing Culture In The Head: The Neural Correlates of Relational Models

Joseph Dien (corresponding author)

Maryland Neuroimaging Center, University of Maryland, 8077 Greenmead, College Park, MD 20742, USA. Phone: 202-297-8117. E-mail: jdien07@mac.com.

Valerie Karuzis

Center for Advanced Study of Language, University of Maryland, College Park, Maryland, 20742, USA. Phone: 301-226-8945. E-mail: vkaruzis@casl.umd.edu.

Henk J. Haarmann

Center for Advanced Study of Language, University of Maryland, College Park, Maryland, 20742, USA. Phone: 301-226-8826. E-mail: hhaarmann@casl.umd.edu.

Short Title: Relational Models

Key Words: neuroimaging, Culture, Social Neuroscience, Self Representation, Numerical Cognition

Dien, J., Karuzis, V., and Haarmann, H. J. (2018). Probing Culture In The Head: The Neural Correlates of Relational Models. Social Neuroscience, 13(6) 648-666.

Address for correspondence: Joseph Dien, Maryland Neuroimaging Center, University of Maryland, 8077 Greenmead, College Park, MD 20742, USA.

Phone: 202-297-8117. E-mail: jdien07@mac.com. URL: http://joedien.com.

Abstract

Relational Models Theory or RMT (Fiske, 1992) proposes that there are four universal ways in which socio-economic relations can be organized. According to the RMT, each of its four relational models (Communal Sharing, Authority Ranking, Equality Matching, and Market Pricing) is associated with a distinct cognitive representation, with a cumulative pattern in which each relational model is a superset of the next lower model. This report for the first time uses a combination of cognitive and the social neuroscience to put this model to the test.

RMT proposes that members of every culture use all four relational models, just in different proportions. It should therefore be possible to study their neural correlates in a mono-cultural sample. In this study, thirty-nine European-American students were imaged in a 3T Siemens Trio with a 24-channel head coil while rating the extent to which each relational model organized relationships with each of thirty-two acquaintances/friend/relatives in a boxcar design. FreeSurfer Functional Analysis Stream (FS-FAST) analyses revealed distinct patterns of activation for each of the relational models. The activations did not follow a cumulative hierarchical pattern, suggestive that this aspect of the RMT model should be revised.

There is currently increasing interest in the convergence of culture and neuroscience resulting in new disciplines of cultural neuroscience (Chiao et al., 2010; Han, 2010; Kitayama & Park, 2010; Verweij, Senior, Domínguez D, & Turner, 2015) and neuroanthropology (Domínguez Duque, Turner, Lewis, & Egan, 2010; Domínguez Duque, Turner, Lewis, & Egan, 2009; Lende & Downey, 2012), especially the rich traditions of anthropology and psychology. A particular challenge in doing so is the crossing of such different levels of analyses.

For example, just because the brain mediates a kind of process, it does not necessarily follow that it will produce a distinctive response in neuroimaging measures. Neuroimaging methods operate best when a patch of contiguous neural tissue on the order of millimeters is responding en masse to an experimental manipulation. If the neurons mediating the process are not organized in such a manner, the response may not be measurable. This is especially the case when one is concerned with high-level concepts like abstract social values as opposed to low-level cognitive operations like face recognition. Furthermore, the finite sensitivity of neuroimaging measures means that a substantial amount of neural activity is required to produce a measurable signal; thus, an easy task or a familiar stimulus may not produce an effect in the region of interest. There are many other limitations on what can be readily captured by neuroimaging methods (Huettel, Song, & McCarthy, 2004).

Given these considerations, while influential cultural models such as Plural Rationality Theory (Douglas, 1970; Verweij et al., 2015) need to be addressed in the long-term, what is immediately needed is a model that is likely to generate measurable neural responses. A theoretical model that meets these criteria is Relational Models Theory or RMT (Fiske, 1992), where the constructs are explicitly defined in neurocognitive terms involving well-studied brain systems. The present study therefore seeks to break new ground by testing for the first time whether cognitive activity related to the four components of RMT can be distinguished using neuroimaging methods.

Relational Models Theory: Relational Models Theory (Fiske, 1992) is founded on the proposition (Fiske, 2004) that there are genetically determined ways of mentally representing socioeconomic relations between pairs of individuals, termed *mods*. Members of cultures, due to their upbringing, utilize these alternative representations to differing extents and these representations in turn result in different behaviors. The manner in which the use of these mods translates into overt behaviors is mediated by *preos*, which are societally-transmitted practices and beliefs and values. For example, two cultures may share a common emphasis on authority relations (a mod) but express it differently, one by bowing and another by saluting (preos). Thus, the use of the same mod in two different cultures could translate into different behaviors that nonetheless share in common a core cognitive foundation. These relational models, combinations of mods and preos, result in “cognitive-affective-motivational models” (Fiske, 2004, p. 9) that help people “construct and construe social action” (Fiske, 2004, p. 21).

According to the RMT (Fiske, 1992), there are four relational models that can be discerned across cultures. Communal Sharing (CS) involves classifying people into in-group and out-groups, with a pooling of in-group resources, as in members of an ethnicity or faith. Authority Ranking (AR) involves representing people in terms of a fixed ordering and results in hierarchical arrangements, as in the US military. Equality Matching (EM) involves keeping track of exchanges and seeking to keep them equal, as in the exchange of gifts or aggression. Market Pricing (MP) involves calculating relative costs and benefits, as in the decisions of employees whether to continue their association with a corporation.

One strength of the RMT is that since its relational models are defined in terms of concrete cognitive operations it is feasible to test this aspect of it with neuroimaging. The Relational Models Theory (Fiske, 1992; Fiske, 2004) proposes that each of the relational models rely on a cognitive operation that corresponds to the four different Stevens measurement scales (Stevens, 1946). Communal Sharing relates to nominal scales in that it involves assigning people to different categories based on similarity, with sharing amongst those in the same category. Authority Ranking relates to ordinal scales in that it involves putting people into ranked orderings. Equality Matching relates to interval scales in that it requires determining not just whether two contributions are unequal but also by how much. Market Pricing relates to ratio scales in that it involves considerations of costs (negatives) and benefits (positives) and their relative magnitudes. Using the Stevens taxonomy as a heuristic, one can readily identify the corresponding functional neuroanatomy, based on the core cognitive operations.

RMT Questions: Great as our appreciation for the manner in which Relational Models Theory enhances anthropological theory with inspirations from cognitive neuroscience, it is perhaps inevitable that as cognitive neuroscientists who are inspired by anthropology, we might beg to differ on some of the details of the cognitive neuroscience. In particular, while the Stevens (1946) classification of measurement scales (i.e., nominal, ordinal, cardinal, and ratio) is structured as a cumulative hierarchy in which each type successively adds a new feature to that of the lower ones and so is the RMT (Fiske & Haslam, 2005, p. 271), we are not aware of any cognitive researchers that make a comparable claim about the psychological processes thus far reviewed.

Instead, the existing consensus can be described as that the brain has a number of ways that it can compute aspects of the world and that some of them are better suited to some types of numeric operations than others. Thus, while the brain is capable of computing second derivatives, it does not follow that there is a brain center dedicated to calculating second derivatives; rather, there are areas that evolved for other purposes but can manage to calculate them and that do so better than other areas. Furthermore, even if in formal mathematical theory multiplication can be considered to be iterated addition, it does not therefore follow that multiplication will involve activation of addition areas plus additional ones allowing for iteration. Just as there are multiple ways to read regular English words (e.g., orthographically and phonologically) and there are multiple ways to formally compute a division operation (e.g., long division, memorized division tables, multiplication by a reciprocal), there are likely different ways that the brain can compute numeric operations, some more efficient than others. Perhaps the best illustration of this principle is the finding (Dehaene, 1994) that the neural basis of counting items from 1-3 (i.e., subitizing), is different from that of counting to higher numbers; the difference is not driven by mathematical principles but rather by the availability of two different neural systems, one of which is more efficient for small numbers of items. Thus, even if there were numeric calculations that formally have some kind of hierarchy, it is not a given that the brain regions used to calculate them will necessarily mirror this arrangement and indeed the evidence suggests that they do not. We therefore do not predict that the brain regions relevant to the relational models have this kind of cumulative structure to them, although this prediction will be evaluated.

Neuroimaging Studies of the RMT: Thus far, there has been only one previous neuroimaging study to evaluate the RMT (Iacoboni et al., 2004). This fMRI study contrasted video clips of two actors interacting in putatively Authority Ranking and Communal Sharing situations and reported a bilateral anterior superior temporal sulcus activation that did not differentiate between the two relational models. It also found increases in the dorsal medial prefrontal cortex (dMPFC) and precuneus areas when comparing scenes with two actors versus those with a single actor. It is unclear whether this study failure reflects issues in the theory or in the experimental design (such as the content of the video vignettes). This ambiguous result illustrates the drawbacks to using highly ecologically valid stimuli from the outset rather than to first use highly controlled stimuli and then work gradually towards more ecologically valid stimuli in successive studies.

The present report builds on this work by, for the first time, outlining the predicted functional neuroanatomy of the RMT in light of the existing cognitive and social neuroscience literature and then putting it to the test. These predictions are made in the context of a task in which the participants are asked in effect to judge the degree to which each relational model applies to a large set of known people (of varying closeness).

Experimental Design: The primary goal of this study is to determine if neuroimaging data can provide divergent validity for the psychometric RMT dimensions by demonstrating dissociable hemodynamic correlates when participants are applying the associated psychometric scales to people they know. The strongest result would be if the four RMT rating tasks were differentially associated with the predicted parts of the brain. As further described in the discussion, we predict that: 1) CS is associated with the ventral medial prefrontal cortex (vMPFC), 2) AR is associated with the dorsolateral prefrontal cortex (dLPFC), 3) EM is associated with the inferior parietal sulcus (IPS), 4) MP is associated with the dorsal striatum. A secondary goal is to test the premise that the relational models operate as a cumulative hierarchy in which each relational model is a superset of the lower relational models.

In order to build on the existing neuroimaging RMT study (Iacoboni et al., 2004), a few changes were made. Since the use of video vignettes did not succeed in differentiating between the relational models, we employed simpler, more easily controlled stimuli, namely written statements. Also, in order to minimize concerns about whether the stimuli are valid operationalizations of the RMT constructs, they were directly drawn from the primary RMT questionnaire battery (Haslam & Fiske, 1999). Furthermore, in order to better elicit relational cognitions, the participants were asked to make judgments about people that they know personally and with whom they already share an existing relationship; additionally, a range of acquaintances were elicited, thereby ensuring that the participants would need to expend mental effort to answer the questions, enhancing neural activity. Finally, all four relational models were tested rather than just Authority Ranking and Communal Sharing.

In the present experimental design, the participants were asked to think about their relationship with acquaintances/friends/relatives, with questions corresponding to the four different relational models in a boxcar design (in which a series of judgments relating to one relational model alternated with a series of judgments relating to a different relational model, facilitating their comparison). The boxcar design was adopted to facilitate a stable attentional focus (to the extent that the relational models are computed by a controlled process) and because a boxcar design is especially sensitive to detecting effects (Friston, Zarahn, Josephs, Henson, & Dale, 1999).

As previously described, each relational model is conceptualized by our team as being independent of the others, so each was contrasted against the other three combined to highlight the cognition of interest while controlling for the cognitive operations that were evoked in common by all four conditions. Thus, while similarity judgment is central to CS (and the CS questions), we do not expect that any significant mental effort will be expended for the other three relational model conditions as it is simply irrelevant to them. One does not need to judge whether another person is similar to oneself to adjudicate authority relations; indeed, a similar other (in terms of appearance, interests, creed, clan, etc. etc.) can be an inferior or a superior (all things being equal). Likewise, we consider the cognitive operations proposed to underlie each of the other relational models as simply independent of the others. Since this view diverges from the original formulation of the RMT (Fiske & Haslam, 2005, p. 271), we will also evaluate this formulation with appropriate contrasts. If the relational models are in fact organized in a cumulative hierarchy, all four will involve the CS operations and so the result should be a null effect. An AR vs. CS contrast will highlight AR specific activity. An EM vs. CS contrast should produce the same activity as AR vs. CS plus EM specific activity. Finally, an MP vs. CS contrast should have the same pattern as EM vs. CS plus MP specific activity. While the EM parietal cardinal representations could certainly in principle mediate AR ordinal computations, we expect that the AR prefrontal representations would be a more efficient approach to doing so (as it would not involve extraneous information about numeric distance, simply ordering), hence people would preferentially utilize them instead of the EM system; one can imagine what would happen if there was an extended thoughtful pause every time a private received an order. Likewise, although the MP ratio basal ganglia affective coding system could in principle be used to mediate ordinal or cardinal computations, we expect that it would not be the most efficient (or accurate) approach and hence will not be used.

For the present sample, the participants were drawn from a culturally homogenous European-American sample in order to avoid complications inherent in differential English proficiencies and trying to match such subsamples. Theoretically, since the cognitive functions (mods) underlying the RMT dimensions are provided by the universal human brain architecture (with degree of use influenced by cultural upbringing), they should be fully available in a European-American sample and potentially elicited with appropriate questions, even if members of this sample are not culturally inclined to spontaneously think in such a manner (e.g., weighing balance of favor trading with an employer). Clearly, generalizing beyond this single cultural sample will be desirable for future studies.

Materials and Methods

Participants: Forty-four European-American participants were recruited for monetary compensation, five of which were excluded, one due to scanner malfunction and four due to inability to finish the session, leaving thirty-nine (mean age 20.6 years; range 18-24 years; 21 females, 18 males). All participants had normal or corrected-to-normal vision, spoke English as a first language, and were born in the United States. No participant reported having any history of psychiatric or neurological disorder. All participants were right-handed, with a mean score of 94.26 on the ten-item Edinburgh Handedness Inventory (Oldfield, 1971). The study was approved by the University of Maryland Institutional Review Board.

For the behavioral replication dataset, an additional fifty native English speakers (mean age 40.0 years; range 18-69; 26 females, 23 males, 1 unknown) were recruited for monetary compensation via Amazon Mechanical Turk. The study was approved by the University of Maryland Institutional Review Board.

Stimuli: The stimuli consisted of 32 single-word names of acquaintances/friends/relatives that were obtained from each participant. The set of statement stimuli was identical for each participant (see Table 1 for the complete list). Each statement in the set was designed to elicit one of the four Relational Models. For each relational model, we used the two statements with the highest factor loading in the definitive 1999 study which introduced the Modes of Relationship Questionnaire, or MORQ (Haslam, 1995; Haslam & Fiske, 1999).

Relational Model	Statement
Communal Sharing (CS)	The two of you tend to develop very similar attitudes and values.
	If either of you needs something, the other gives it without expecting anything in return.
Authority Ranking (AR)	One of you directs the work you do together-the other pretty much does what they are told to do.
	One of you is the leader, the other loyally follows their will.
Equality Matching (EM)	If you have work to do, you usually split it evenly.
	You typically divide things up into shares that are the same size.
Market Pricing (MP)	You have a right (you are entitled) to a fair rate of return for what you put into this interaction or how much they did.
	What you get from this person is directly proportional to how much you give them.

Table 1: Stimulus Sentences. The scale was: 1=“Almost never”, 2=“Occasionally”, 3=“Usually”, and 4=“Almost Always.”

Procedure: Upon arrival, subjects provided informed consent and were safety-screened. Before entering the scanner, each participant was asked to list 32 unique single-word names/keywords of acquaintances/friends/relatives with whom he or she interacted (e.g., “mom” or “Fred”). Each participant was told that they would be asked to rate the degree to which their relationships with these individuals were true with a given set of statements. The names were collected via LimeSurvey (Schmitz, 2012) on a computer at the scanner facility prior to the scanning.

The functional experiment within the scanner consisted of four runs (five minutes and 33 seconds each) presented in a boxcar design (Figure 1). The boxcars consisted of eight cycles of two different alternating conditions, each with four trials each. For a given participant, the same two relational models were paired (e.g., “AR” and “CS”), counterbalanced across participants. For each participant, which of the two boxcars came first was randomized. There were an additional four runs implementing a manipulation that subsequent norming indicated was psychometrically problematic and so they were dropped from the analysis.

For each trial, a statement (e.g., “If you have work to do, you usually split it evenly.”) was presented on the screen for 1.016 seconds, followed by the name of an acquaintance for 4.050 seconds. Participants were asked to respond via button press (1-4) the degree to which the statement was true for the participant’s relationship with the person listed. The anchors used for making these judgments were “Almost Never”, “Occasionally”, “Usually”, and “Almost Always”. The order of the anchors (left to right) was counterbalanced among participants. The order of the names was randomized for each run.

Data Collection: Functional MRI data were acquired using a gradient echoplanar imaging (EPI) sequence on a 3T Siemens MAGNETOM Trio Tim scanner at the Maryland Neuroimaging Center at the University of Maryland, College Park. A 32-channel headcoil was used. Functional data were scanned using single-shot gradient EPI imaging fMRI scans consisting of 36 ascending interleaved axial slices (TR/TE = 2000/24, flip angle equal to 70 degrees, field of view equal to 192 mm, matrix equal to 64x64, slice thickness equal to 3.0 mm with a 0.9 mm interslice gap, in plane resolution equal to 3.0 x 3.0 mm). The scans for each block began after the scanner completed its calibration with dummy volumes. Inspection of the resulting data revealed further T1-stabilization artifact so an additional two volumes were dropped, leaving 165 reps per run. Stimuli were presented to participants via a projector screen at the participants' feet. This projector was connected to the presentation PC in the control room. E-Prime version 2.0.8.22 was used to present the experiment (Psychology Software Tools, Inc., Pittsburgh PA).

Anatomical MR data consisted of T1-weighted images using a 3D MP-RAGE sequence (TR/TE = 1900/2.32, flip angle of 9 degrees, field of view equal to 230 mm, 0.9 mm isotropic voxels, and 192 slices). A vitamin E capsule was used to confirm L/R orientation of the image.

Data Analysis: The analyses were conducted using FreeSurfer 5.3.0 (Fischl, 2012) (Martinos Center for Biomedical Imaging, http://surfer.nmr.mgh.harvard.edu/fswiki/FreeSurferWiki) on an Intel 64-bit Mac Pro running OS X 10.12.5 and Matlab 2016b. First, cortical reconstruction was performed on the T1-weighted anatomical images. Then, preprocessing was conducted on the functional images using the FS-FAST (Freesurfer Functional Analysis Stream) module, realigning it, dividing into three spaces (left and right hemisphere surfaces and MNI305 subcortical volume), and smoothing it with a 5mm FWHM (full width-half maximum) kernel. FS-FAST has the particularly powerful feature that it operates on the cortical surface, reducing both the multiple comparison problem and smoothing-induced contamination between adjoining surfaces. This surface-based procedure is applied to each hemisphere separately, resulting in two separate spaces. The subcortical region is not amenable to this surface-based approach and so is analyzed as a separate third space using standard volumetric procedures. ArtDetect-2011-07 (http://www.nitrc.org/projects/artifact_detect/) was used to detect bad data (using a modified version able to read FS-FAST data) with default settings.

FS-FAST was then used to compute the first-level contrasts using an SPM canonical HRF (hemodynamic response function) with no time derivative or dispersion terms. The regressors consisted of the four relational models (AR, CS, EM, MP), modelled as four-second events with onsets corresponding to the presentation of the names. In addition, the one-second question events from all four conditions was included as a baseline condition, based on the reasoning that the cognitive process of interest could not begin until the target name was presented and it would control for generic reading processes. In addition, the six movement estimates were used as nuisance regressors. Finally, the bad reps identified by the ArtDetect procedure were nulled via rep-specific regressors.

The planned contrasts were each of the four relational model conditions against the three others (e.g., 3*CS vs AR+EM+MP). Additionally, in order to evaluate the cumulative view of the relational models, AR, EM, and MP were contrasted individually against CS (e.g., AR vs. CS). This view would predict that the EM vs. CS contrast would have largely the same pattern of significant areas as the AR vs. CS contrast plus some additional areas (especially the IPS region of interest or ROI) and that the MP vs. CS contrast would have those of the EM vs. CS contrast plus additional areas (especially the caudate ROI). The contrasts were carried out as conventional one-way t-tests.

Second level analyses were conducted using weighted least-squares to take into account subject-specific variances. For the main effects analyses, the contrasts were conducted with no covariates. Voxelwise height thresholds were set at p = .01. and clusterwise correction for multiple comparisons at the .05 level was conducted.

The ROI analyses (Figure 2) were performed for CS with a spherical ROI (based on MNI coordinates rather than surface space) centered on the coordinate [16 44 -4] implicated in a similarity reasoning study (Koenig et al., 2005) and with a 16 mm radius in order to encompass the area implicated by attitudinal similarity studies (Mitchell et al., 2005; Mitchell et al., 2006). The Desikan-Killiany Atlas parcellations (Desikan et al., 2006) were used for AR (rostral middle frontal) and EM (inferior parietal) since it contained regions with suitable boundaries and the Atlas boundaries are less arbitrary than a spherical ROI. For MP, the caudate was identified using an automated subcortical atlas (Fischl et al., 2002). The mean of the first level betas in the ROI voxels were taken for the appropriate condition predictors, scaled by the run baseline betas, and contrasted *a priori* using a dependent measures 2-tailed t-test. The mean squared error (MSE) for the dependent t-tests calculated based on the pooled variances and the mean difference (MD) are provided to facilitate the proper calculation of effect sizes (Dunlap, Cortina, Vaslow, & Burke, 1996; Lakens, 2013). Note that the t-statistic should not be calculated from the provided MSE and MD as the dependent t-test MSE is calculated based on the difference scores.

Coordinates presented in this report are in MNI (Montreal Neurological Institute)-space. Determination of Brodmann Areas and anatomical features corresponding to activation peaks was performed by using the Talairach Daemon project's talairach.nii file, which converts the MNI coordinates to Talairach Atlas space using the Lancaster transform (Laird et al., 2010; Lancaster et al., 1997; Lancaster et al., 2007) in order to reference the contents of the Talairach Atlas (Talairach & Tournoux, 1988). The closest gray matter label is used for each such coordinate, but unlike the Talairach Client if there is a tie in distance then both labels are presented. Also, the cortical surface spaces were restricted to cortical labels and the subcortical space was restricted to subcortical labels.

Results

Behavioral Data: Unfortunately, due to a programming error, the behavioral data from the relational model judgments are unavailable for all but the final seven participants (Table 2). The mean scores suggest that the ratings for all cells were largely comparable. Questionnaire data from an additional set of respondents were collected per reviewer request to demonstrate that the means of the two scales for each relational model were generally similar to each other (Table 3), which they were.

Relational Model	Scale1	Scale2
Communal Sharing	2.21	2.07
Authority Ranking	2.67	2.93
Equality Matching	2.15	2.07
Market Pricing	2.34	2.29

Table 2: Means of Relational Models Behavioral Data. The scale was: 1="Almost never", 2="Occasionally", 3="Usually", and 4="Almost Always." Scale1 and Scale2 provide the means for the two scales used for each relational model. See Table 1 for the exact wording of the scales. Scale1 is the first statement and Scale2 is the second statement listed for each relational model.

Relational Model	Scale1	Scale2
Communal Sharing	2.43	2.73
Authority Ranking	2.04	1.98
Equality Matching	2.59	2.80
Market Pricing	2.53	2.43

Table 3: Means of Relational Models Replication Behavioral Data. The scale was: 1="Almost never", 2="Occasionally", 3="Usually", and 4="Almost Always." Scale1 and Scale2 provide the means for the two scales used for each relational model. See Table 1 for the exact wording of the scales. Scale1 is the first statement and Scale2 is the second statement listed for each relational model.

fMRI Data: First, the premise that the relational models are arranged in a cumulative hierarchy was examined via the three planned contrasts in Table 4. No evidence was seen to support the contention of a cumulative hierarchy.

Cluster p	Size	Peak p	Peak T	Coords	BA	Anatomical Landmark
AP > CS						

n.s.						
CS > AP						
n.s.						
EM > CS						
0.001	528	0.811	5.30	-34 -80 34	19	Left Precuneus
CS > EM						
0.026	335	1.000	3.59	-36 -89 -9	18	Left Inferior Occipital Gyrus
0.033	334	0.973	3.86	20 -98 -13	17	Right Lingual Gyrus
					18	Right Lingual Gyrus
0.024	2632		3.98	26 -83 -25	--	Right Posterior Uvula of Cerebellum
MP > CS						
0.000	1003	0.822	5.18	-17 -95 -6	17	Left Lingual Gyrus
0.001	534	0.509	4.57	15 -92 5	17	Right Cuneus
CS > MP						
0.000	636	0.781	5.56	-5 24 -4	24	Left Anterior Cingulate
0.000	1450	0.820	5.08	-16 -58 16	30	Left Posterior Cingulate
0.000	877	0.877	4.69	-42 -75 19	39	Left Middle Temporal Gyrus
0.002	507	0.957	4.23	-38 -83 3	18	Left Middle Occipital Gyrus
0.040	312	0.980	4.06	-24 -45 -7	37	Left Parahippocampal Gyrus
0.000	1298	0.139	5.33	38 -66 15	19	Right Middle Occipital Gyrus
0.001	508	0.530	4.55	8 33 -8	32	Right Anterior Cingulate
0.000	864	0.590	4.48	18 -56 9	30	Right Posterior Cingulate
0.010	388	0.858	4.13	49 -16 -18	20	Right Sub-Gyral Temporal Lobe
0.000	10496		4.57	-4 5 -5	--	Left Caudate Head
0.000	5336		4.35	8 -39 -5	--	Right Anterior Culmen of Cerebellum

Table 4: **Main Effects Testing for a Cumulative Hierarchy.** Cluster p-values are FWE corrected. Size is square mm for surface-based analyses and cubic mm for volume-based analyses. Peak p is FWE-corrected peak vertex p-value. Peak T is peak vertex value. Coordinates are MNI coordinates of the peak vertex. Vertex threshold set at p=0.01. BA is Brodmann Area. Peak p-values are not available for volume-based analyses due to software limitations.

For the ROI analyses, the planned comparisons for CS > Others in the rostral anterior cingulate region of the left (t[38]=0.53, MSE=0.0056, MD=0.0066) and right (t[38]=1.24, MSE=0.0057, MD=0.017) hemispheres were not significant. The planned comparison for AR > Others in the rostral middle frontal cortex of the right (t[38]=2.063, MSE=0.0079, MD=0.031, p=.046) but not left (t[38]=1.69, MSE=0.0073, MD=0.024) hemisphere was significant. Also for

MP > Others in the caudate of the left hemisphere (t[38]=-3.50, MSE=0.0041, MD=-0.028, p=0.0012) but not the right hemisphere (t[38]=-1.01, MSE=0.0053, MD=-0.012) was significant. The planned comparisons for EM > Others in the inferior parietal cortex of the left (t[38]=-0.40, MSE=0.0065, MD=-0.0050) and right (t[38]=0.52, MSE=0.071, MD=0.0007) hemispheres were not significant.

Activation patterns corresponding to all four relational models were obtained as both main effects (Table 5 and Figure 3) using a whole-brain analysis.

Cluster p	Size	Peak p	Peak T	Coords	BA	Anatomical Landmark
CS > Others						
0.017	2728		4.04	28 -83 -33	--	Right Posterior Pyramis of Cerebellum
AR > Others						
0.002	518	0.859	4.84	-52 -6 46	4	Left Precentral Gyrus
0.037	323	0.961	4.21	-50 -49 14	22	Left Superior Temporal Gyrus
0.044	312	0.905	4.04	20 38 36	9	Right Superior Frontal Gyrus
EM > Others						
0.002	513	0.768	6.07	-10 -58 10	30	Left Cuneus
0.001	564	0.829	5.09	-34 -80 35	19	Left Inferior Parietal*
0.002	520	0.908	4.53	-31 -47 -6	19	Left Parahippocampal Gyrus
0.004	449	0.147	5.28	32 -31 -17	36	Right Parahippocampal Gyrus
0.000	1000	0.460	4.63	40 -69 17	39	Right Middle Temporal Gyrus
0.016	381	0.778	4.23	15 -53 8	30	Right Posterior Cingulate
0.043	2360		4.28	-34 -43 -9	--	**
Others > EM						
0.000	1904	0.815	5.16	-31 -90 -16	18	Left Fusiform Gyrus
					18	Left Inferior Occipital Gyrus
0.017	361	0.888	4.62	-42 1 42	6	Left Middle Frontal Gyrus
0.000	1939	0.416	4.71	12 -90 -8	17	Right Inferior Occipital Gyrus
MP > Others						
0.000	1775	0.803	5.39	-17 -96 -4	18	Left Lingual Gyrus
0.000	931	0.232	5.04	14 -91 7	17	Right Cuneus
Others > MP						
0.000	3539	0.718	7.93	-16 -58 17	30	Left Posterior Cingulate
0.000	2111	0.751	6.27	-40 -74 22	39	Left Middle Temporal Gyrus
0.001	560	0.801	5.30	-6 21 -9	32	Left Anterior Cingulate
0.000	647	0.956	4.24	-14 -51 36	31	Left Precuneus
0.000	2720	0.006	7.23	38 -66 17	39	Right Middle Temporal Gyrus
0.000	3319	0.015	6.74	12 -57 19	31	Right Precuneus
0.006	404	0.713	4.33	8 33 -8	32	Right Anterior Cingulate
0.004	418	0.824	4.18	53 -48 26	40	Right Supramarginal Gyrus

0.000	19416		5.85	30 -33 -17	--	Right Anterior Culmen of Cerebellum
0.000	13984		5.17	-22 -63 -49	--	Left Posterior Inferior Semi-Lunar of Cerebellum
0.000	4376		5.02	36 -59 -53	--	Right Posterior Tonsil of Cerebellum
0.000	5896		4.98	-4 5 -7	--	Left Caudate Head

Table 5: **Results of Main Effects Analyses.** Cluster p-values are FWE corrected. Size is square mm for surface-based analyses and cubic mm for volume-based analyses. Peak p is FWE-corrected peak vertex p-value. Peak T is peak vertex value. Coordinates are MNI coordinates of the peak vertex. Vertex threshold set at p=0.01. BA is Brodmann Area. Peak p-values are not available for volume-based analyses due to software limitations. *=incorrectly labeled by the Talairach Client. **=apparent segmentation fault resulting in some cortical activation spilling over into subcortical volume.

Discussion

As hypothesized, the four relational models were associated with differing patterns of neural activation in this cultural sample. Furthermore, activations from two of the four relational models displayed regions of activation one might predict based on the existing literature (ROIs) while whole brain analyses included significant activations for the other two. This finding provides the first neuroimaging support for the RMT model's proposition that each relational model is associated with a distinct cognitive function. On the other hand, there was no evidence for RMT's proposition that the relational models are organized in a cumulative hierarchy.

If there is a cumulative hierarchy between the relational models, then each of the successive contrasts (AR vs. CS, EM vs. CS, and MP vs. CS) in Table 4 should have been a superset of the prior contrast. Even the reverse contrasts (CS vs. AR, CS vs. EM, and CS vs. MP) did not have this kind of pattern. While any kind of null effect can be due to insufficient statistical power (and indeed including only two conditions in the contrast likely reduced the statistical power compared to the "vs. Others" contrasts that used all four conditions), the parsimonious interpretation is that the neurocognitive activity mediating the four relational models are not a cumulative hierarchy; instead, each one is associated with activity in a distinctive set of brain regions. The RMT is not in any way weakened by such a finding as it is a peripheral tenet that can be dropped without any effect on the overall model. This then provides an example of how neuroscience studies can contribute to the development of the RMT model.

Regarding the one prior fMRI study (Iacoboni et al., 2004) of the RMT, the present results further support the inference that the bilateral anterior superior temporal sulcus activation found in that study are not specific to the relational models. In that study, the activations did not distinguish between the two relational models tested (AR and CS). Such an activation was not observed in the present study. It is likely that it reflected some aspect of the video stimuli and/or accompanying speech. Alternatively, it is possible that this region was equally activated by all four RMT conditions and therefore was not significant for any of the contrasts.

Regions of Interest: Before proceeding, it is important to explain that we make these predictions with great reluctance. It would be highly unlikely that each cognitive process would be localized to one and only one cortical region. We choose each region of interest (ROI) as merely one area that seems to participate in the cognitive process of interest, likely as part of a network. Furthermore, we do not intend to engage in reverse inference. At least according to Poldrack (2011), reverse inference is "to reason backward from patterns of activation to infer the engagement of specific mental processes" (p. 692). He goes on to say that "reverse inference can be a very useful strategy" (p. 696) and that "The problem with this kind of reasoning arises when such hypotheses become reified as facts" (p. 696). So, for example, concluding that a task involves working memory because the dLPFC is activated would be a case of reverse inference because it assumes that the dLPFC is not just activated in working memory tasks, which is well demonstrated, but that it is only activated in working memory tasks, which is merely a hypothesis. We do think, however, that findings from neuroimaging studies may be used to suggest hypotheses that can then be tested. Thus, dLPFC activation would not be conclusive evidence of working memory involvement in a relational model but it would suggest that working memory might be worth investigating.

The motivation for the ROI predictions is to respond to feedback on this report that predictions must be made with which to evaluate the results. So, the intention is not that each cognitive operation is associated with just one cortical area but rather that if the relational model involves this cognitive operation then, based on existing literature, that cortical area should be activated. In the present case, the only inference made is that since an ROI has been activated in a given type of cognitive task, if the relational model also involves making that kind of cognition then that ROI should also be activated. Whether such activation occurs because that area is specifically devoted to that kind of cognition or whether it is simply contributing in some kind of ancillary role is left undetermined and no such claim is made. Poldrack himself notes of reverse inference (ibid, p. 692) that "At the same time, a number of researchers have argued that it is a fundamentally important research tool, especially in areas such as neuroeconomics and social neuroscience, in which the underlying mental processes may be less well understood." In sum, we quite agree that an overemphasis on hypothesis making risks making errors of reverse inference at such an early stage of investigation. Solid science requires an initial stage of exploratory research to accumulate observations before rigorous hypothetico-deductive reasoning can proceed. While we think making strong predictions is somewhat premature given the state of the literature and thus making strong predictions leaves one open to criticism, not making the effort also leaves one open to criticism. Here we make our best effort to thread between these two conflicting concerns.

Communal Sharing: By definition, the core cognitive operation for Communal Sharing is that of similarity judgment, which in a sense determines who is sufficiently similar to the self as to be treated as an extension of the self and hence one's resources. Simple tests of the most developed cognitive neuroscience model of similarity judgment, the COVIS or Competition between Verbal and Implicit Systems model (Ashby et al., 1998), have thus far yielded mixed results (Carpenter et al., 2016; Milton & Pothos, 2011; Nomura et al., 2007). From the cognitive perspective, the present study's CS task can be thought of as sorting multi-dimensional stimuli (i.e., people) into a newly formed category (insofar as they are unlikely to have previously applied the CS rating scales) via similarity judgments. Of the three studies (Koenig et al., 2005; Milton et al., 2009; von Helversen et al., 2014) that involved such a task, no areas were consistently activated across all studies. Thus, the existing literature on similarity judgment is thus far of limited utility for the present case.

More apparently promising are consistent findings that the right inferior prefrontal gyrus (RIFG) is implicated in processes such as similarity judgments (Garcin et al., 2012) and novel metaphors (Mashal et al., 2007). However, it has been suggested (Giora, 1997) that the RIFG’s role in this kind of task is not computing similarity *per se* but rather suppression of more obvious interpretations (e.g., "dark day" as meaning reduced light, allowing metaphorical meanings to become salient) consistent with a general role in inhibition (Aron et al., 2004); thus, such a role could complement Communal Sharing mentation insofar as perceiving someone as similar may require ignoring salient dissimilar characteristics (e.g., skin color) but it could not be expected to be predictably activated in the present task. The cognitive neuroscience literature therefore does not provide clear guidance for CS.

Turning to social neuroscience, it has been suggested that the process of empathy can help facilitate Communal Sharing (Rai & Fiske, 2011), although Fiske has offered a more complex account of how the relational models are related to feelings like empathy (Fiske, 2002). While empathy is typically studied in the context of pain, it is here of interest only insofar as it might be illustrative of empathy in general. Certainly, empathy is mediated in part by a sense of identification and is enhanced by perceived similarity (Avenanti et al., 2010; Azevedo et al., 2013; Heinke & Louis, 2009; Houston, 1990; Huang & Han, 2014; Lamm et al., 2010; Nelson & Baumgarte, 2004; Nelson et al., 2003). Reviews (Bernhardt & Singer, 2012; Fan et al., 2011; Lamm et al., 2011; Seitz et al., 2006) have implicated bilateral anterior insula and anterior midcingulate cortex for empathy mediated by direct observation of pain. The latter is particularly interesting as it has been observed (Van Overwalle & Baetens, 2009) that the vMPFC is especially involved with both self and familiar other trait inferences, which is consistent with it having a central role in determining similarity of the self to others in one's in-group, and indeed neuroimaging studies of in-group processes in general have implicated this region (Molenberghs, 2013).

Furthermore, the vMPFC [16 44 -4] was reported to be active in one study of similarity reasoning (Koenig et al., 2005), although it has also been suggested that this region is specialized for social cognition (Van Overwalle, 2011). A nearby area also responds to the similarity of those about whom one is inferring attitudes [9 57 3] and [18 57 9] (Mitchell et al., 2005; Mitchell et al., 2006; Mobbs et al., 2009). Although one study (Krienen et al., 2010) reported that the vMPFC responds to perceived social closeness rather than similarity, it is quite possible that the limited information provided in the "brief fictitious biographies" provided for the "similar" strangers was not sufficient to make them seem more similar to the participants than their real-life "dissimilar" friends; for example, a similar sense of humor would not be captured by the attitudinal scales used to construct the biographies). Thus, the anterior insula and the vMPFC are the leading candidates for involvement in Communal Sharing mentation; since the insula is also involved in the processes suggested for Market Pricing it will be ignored and only the vMPFC will be considered.

Turning to the specifics of the RMT activations, the Communal Sharing planned contrast did not produce the expected vMPFC activation. What was observed was a right cerebellar activation in the whole-brain analysis. The locus of this cluster [28 -83 -33] was almost exactly the same [26 -86 -32] as that reported in a cerebellar social cognition meta-analysis (Van Overwalle, Baetens, Mariën, & Vandekerckhove, 2014) for mentalizing about the traits of close and distant others, which was also the nature of the task in the present study. This close correspondence provides assurance of the validity of this effect, although the current uncertainty about the role of the cerebellum means that further interpretation of this effect will have to await further research. What was not seen was activity in areas implicated in similarity cognition. Determining whether this absence is a Type II error or theoretically significant will require further study.

Authority Ranking: According to RMT, the core cognitive representation for Authority Ranking is ordinal ranking. In essence, this means the ability to mentally maintain ordered lists where there is no distance information about spacing between items. An in-depth review of both human and monkey data in Nature Reviews Neuroscience concluded that such a mental capacity is most associated with the lateral prefrontal system (Nieder, 2005), which is the portion of the prefrontal cortex which mediates working memory and formulates mental programs of action including counting (Kansaku et al., 2007). While some studies of ordinal information such as days of the week have suggested parietal involvement (Pariyadath et al., 2012; Zhang et al., 2016), it seems clear that one cannot rule out the possibility that days of the week are actually represented as interval scales. In practice, days of the week are equally spaced 24-hour periods and may therefore be represented as an interval scale.

Social neuroscience is also supportive of this prediction, although the literature is not nearly as clear as the cognitive literature. For example, research on obedience processes (the response to authority) has been rather limited since the Milgram experiment (Milgram, 1974). Available research suggests that the premotor areas may indeed be implicated for AR. This observation is significant because the premotor regions (especially the rostral portion) are not motor regions per se so much as executive control regions that are engaged in aspects of planning (Goldberg, 1985; Hanakawa, 2011; Passingham, 1993; Picard & Strick, 2001; Rizzolatti et al., 2002) beyond their role in the mirror neuron system (Rizzolatti & Sinigaglia, 2010). When a subject followed verbal instructions on how to move his/her hand, both the supplementary motor area (SMA) and the lateral premotor area (LPA) were activated (Roland et al., 1980). The LPA is also activated when taking turns in a go-nogo paradigm with a partner compared to having the partner sit passively (Sebanz et al., 2007), which can be thought of as a type of obedience insofar as one makes the choice at the outset to accept the constraint on one's freedom of action and thenceforth responds accordingly. Furthermore, it has been proposed in a well-received Brain and Behavioral Sciences review (Greenfield, 1991) that the ventral LPA (roughly) has a role in utilizing hierarchical representations, which are also characteristic of social authority structures.

A limitation to these studies is that they involve programming complex motor actions and the current task involves little more than button presses. More promisingly, one report (Farrow et al., 2011) found that judgments about the relative social ranking of two famous people (e.g., Prince Harry and Queen Elizabeth) activated a ventral LPA area compared to questions about age, gender, or fame. While this does imply the involvement of ventral LPA in comparisons involving cardinal stimuli, it is not clear from the description of the stimuli whether the stimulus personages being compared were indeed part of the same authority structure (and hence directly in terms of AR) or whether they were being compared as two individuals in the abstract (and hence not necessarily in terms of AR).

Even more relevant was a study where a simulated hierarchy was established based on a computer game. One player was labeled as being better than the participant and another player was labeled as being worse. This study showed dLPFC effects when observing pictures of the better player compared to the worse player (Zink et al., 2008). Thus, the dLPFC may be the stronger candidate of the two for the present study. We therefore predict that when participants are asked to evaluate the Authority Ranking aspects of their relationships with others, they will use the dLPFC to envision themselves with respect to relative ranking.

With regards to Authority Ranking, the planned contrast in the right rostral middle frontal ROI was significant. Furthermore, there was also an AR whole-brain main effect in the prefrontal region, although not the dLPFC or premotor cortex. The whole brain effect was more dorsal and posterior than the ROI so they did not exactly correspond but both are generally consistent with the hypothesis. For example, the whole-brain effect was near the same right hemisphere region that was shown by an fMRI-rTMS (repetitive transcranial magnetic stimulation) study (Dambacher et al., 2014) to be involved in action restraint using a Go/No-go task. In other words, when this portion of the brain was disrupted (right hemisphere only), participants had difficulty restraining themselves from responding to the rare No-go cues embedded in a stream of Go cues. This makes sense insofar as an authority-conforming mindset requires inhibiting oneself from acting outside the dictates of one's role. It is probably not a coincidence that strongly AR settings tend to be characterized by rigid body postures, as in standing at attention, saluting, bowing, and so forth. It therefore makes sense that when the participants were asked to consider their AR relationships that this area became active, whether or not it was directly required to answer the questions. Perhaps this is why there was also a left precentral relative activation (reduced deactivation) in the whole-brain analysis.

Additionally, there was a significant main effect in the left superior temporal gyrus. This temporo-parietal junction (TPJ) area tends to be activated in social cognition studies (Shkurko, 2012; Van Overwalle, 2009; Van Overwalle, 2011) and it has been suggested that it may serve to help infer social goals and intentions (Van Overwalle, 2009). It may be that adopting a more authority-oriented perspective promotes such social inferences (in order to make judgments about the proper exercise of submission to authority), resulting in lessened deactivation.

Equality Matching: According to RMT, Equality Matching rests on the mental representation of interval scaling, which is to say cardinality. This differs from ordinal scaling in that there is also information about the distance between the items, not just their ordering. The relevant cognitive neuroscience literature is especially robust in pointing towards a central role for the intraparietal sulcus or IPS (Arsalidou & Taylor, 2011; Brannon, 2006; Cappelletti et al., 2010; Dehaene et al., 1998; Eger et al., 2003; Kadosh & Walsh, 2009; Nieder, 2005; Nieder et al., 2006; Pinel et al., 2001; Santens et al., 2010) and the bordering angular gyrus (Göbel et al., 2001). This region appears to mediate a spatially organized number line representation that is suitable for computing interval scaling.

If, as noted earlier, one can represent information such as the days of the week as either ordinal or interval, one might ask why one might need posit two different neurocognitive mechanisms. One possible answer is that some things can be represented either way but other things would be distinct to one or the other system. For example, it might be that the prefrontal working memory system is better suited for representing ordinal lists of qualitatively different items whereas the parietal system gains its ability to represent the interval spacing between items at the cost of being less capable of representing unique item characteristics.

The social neuroscience literature provides strong support for generalizing this observation to the social domain. A particularly relevant study (Yamakawa et al., 2009) demonstrated that the left IPS was activated by both a spatial distance task (which of two textures is closer) and a judgment of personal distance (judging potential social compatibility of a face with oneself). However, it was not activated when judging general popularity of these same faces, which does not involve a judgment of personal social distance.

Note particularly the distinction here between relational cognition (personal distance between oneself and the other person) and person impression (general popularity independent of the participant). The present RMT framework is only meant to apply to cases where a social relationship, potential or existing, is being evaluated. In more general person impression situations, one would expect many processes to be involved. Studies that have presented pictures of other people in the absence of a relational context have reported varied activations such as vMPFC and IPS (Cloutier et al., 2012), precuneus, dMPFC and vMPFC (Muscatell et al., 2012), and ventrolateral prefrontal cortex, vMPFC, and superior temporal cortex (Marsh et al., 2009). While clearly relevant to relational cognition, the varied results in just this set of reports demonstrates that it would require a greatly expanded theoretical framework to account for the additional dynamics at work in an impression formation task. Some discussion of such issues is available elsewhere (Mason et al., 2014).

As another example, while the finding (Chiao et al., 2009) that judgments of military rank symbols by Naval Reserve Officer Training Corp midshipmen activated the IPS might seem to implicate the IPS in Authority Ranking (ordinal scaling) as well, we argue that this is not the case. In a normal authority situation, when an officer gives an order to a midshipman, it does not matter by how much the officer outranks the midshipman, s/he needs to obey regardless (hence ordinal scaling)[1]. We suggest that the IPS was activated in this study only because it implicitly encouraged the participant to arrange the rank insignia on a mental number line to efficiently accomplish the task, which we suggest is not the case for normal authority situations and is not the case for the present task. Thus, we predict that the IPS and adjoining inferior parietal cortex will be activated by the EM main effect and only the EM main effect.

For the Equality Matching > Others contrast, results did not support the hypothesis. As reflected in the null result for the planned contrast, there was no evidence of activation in the IPS, the region most implicated in ordinal numeric computation. In an example of how brain imaging results might help inform theory development, there were bilateral inferior parietal relative activations (increased activation in the LH, decreased deactivation in the RH) in the whole-brain analysis. This region is part of the TPJ region frequently implicated in theory-of-mind cognition (Van Overwalle, 2009). While directly concluding that EM involves such theory-of-mind cognition instead of IPS numeric cognition would be a case of unwarranted reverse inference, it is nonetheless a thought-provoking observation that suggests it might be productive to direct future experiments at the possibility that EM (which after all operates in the social domain) involves theory-of-mind computations more than simple arithmetic and to a greater extent than the other relational models.

Unexpectedly, the Equality Matching > Others contrast yielded a medial parietal activation. One possible account is that Equality Matching necessarily relies on one's memory of past transactions and the medial parietal has been implicated in memory retrieval (Vilberg & Rugg, 2008). Such a view might also explain the activation in the bilateral parahippocampal gyri as the hippocampus is centrally involved in memory processes (Squire, 1992).

There were also deactivations for the EM > Others contrast in a number of regions, which may simply reflect that these areas are more active for some of the other relational models. In other words, if an area is significantly more active for an AR > CS+EM+MP contrast, it is guaranteed to be relatively deactivated (although not necessarily statistically significant) for an EM > AR+CS+MP contrast. Whether such an effect is best described as an activation in the one case or a deactivation in the others is an ambiguity inherent in the analysis. Given the nature of the contrasts in the present experiment, we tend to put more weight on activations versus deactivations and will for the most part ignore the relative deactivations.

Market Pricing: Finally, according to RMT, the mental representation of ratio scales lies at the heart of Market Pricing. Compared to interval scaling, ratio scaling adds the capability of weighing costs (negatives) versus benefits (positives). While it is true that ratio scaling could be said to be a superset of interval scaling and thus not different in kind, the key difference is that it involves separate cognitive representations of positive and negative values that can be summed together. Whereas two points on an interval scale differ only in magnitude, a negative point on a ratio scale is different in kind from a positive point. Or to put it a different way, it is suggested that the interval scaling of EM is implemented as a spatial number line whereas the ratio scaling of MP is implemented as mixed feelings of likes and dislikes.

Functional neuroimaging studies indicate that the neural network that implements such ratio affective coding is at least in part distinct from that which implements ordinal number line coding. A recent explosion of research into decision-making and neuroeconomics has helped delineate a network of modules that carry out just such computations using affectively coded values of positive and negative attitudes. This is a modification of the RMT because it has been stated that Market Pricing is different from the other relational models in that it is primarily cognitive in nature rather than affective (Fiske, 2004, p. 15). In contrast, while we agree that all socioeconomic relations involve affective elements, we suggest that Market Pricing is uniquely reliant on computing via affective coding of costs and rewards. As described in more detail elsewhere (Dien et al., 2011), we suggest that nomadic cultures are especially vivid examples of Market Pricing. Leaders attract followers by maximizing positive reputations for attributes such as honor, generosity, and martial skill, and by minimizing negative reputations, with groups fluidly waxing and waning in this free market of reputation. This view of social space, in which affiliation is determined by the sum effect of competing affective attractions and repulsions, can be likened to Lewin's classic Force-Field Theory (Lewin, 1939), which modeled a person's motivational space as being an array of force vectors from both internal and external sources.

The relevant literature of social neuroeconomics is currently quite active with a host of competing models (Boorman et al., 2013; Burke et al., 2013; Croxson et al., 2009; Diekhof et al., 2012; Grabenhorst & Rolls, 2011; Kable & Glimcher, 2009; Kahnt & Tobler, 2013; Knutson et al., 2007; Kurniawan et al., 2013; Liu et al., 2011; Park et al., 2011; Prevost et al., 2010; Sanfey & Chang, 2008; Rushworth et al., 2011; Talmi et al., 2009) revolving around the orbital frontal cortex (OFC), ventral medial prefrontal cortex, dMPFC, dorsal striatum (caudate and/or putamen), ventral striatum (nucleus accumbens), dorsolateral prefrontal cortex (dLPFC), and anterior insula. There is general agreement that the amygdala, orbital frontal cortex, dorsal striatum (caudate and putamen), ventral striatum (nucleus accumbens), and anterior insula play the central roles in affective coding, and hence are the leading candidate areas for Market Pricing specific mentation.

Of these structures, the best candidate is the dorsal striatum for an ROI. The amygdala is a small structure and difficult to visualize unless the scanning parameters are optimized for it. The orbital frontal cortex is difficult to measure because it suffers from susceptibility artifact from the proximity of the sinuses. The insula is also implicated in CS and so lack specificity. The caudate portion of it seems especially promising. A body of studies have utilized trust games in which the task (e.g., Fareri et al., 2012) involves the participant deciding whether to keep money they were given ($1 earned) or to invest it with the unseen partner (multiplying it to $3). The risk in this task is that the partner then either shares the money (both earn $1.50) or keeps the full amount (participant gets nothing). We suggest that, over many such trials, this task lends itself better to a probabilistic cost-benefit analysis (and hence Market Pricing) than strict favors given/received accounting (and hence Equality Matching). Keeping in mind our view that Market Pricing relationships are characterized by fluid choices of whom to associate with and whom to avoid, with reputation being a prime determinant of cost-benefit considerations, it is especially relevant that the caudate responds to reputation in trust games (Delgado et al., 2005; Fouragnan et al., 2013; King-Casas et al., 2005; Stanley et al., 2012; Wardle et al., 2013), although views of its functional role varies (but see Fareri et al., 2012). Thus, for the present case, it is therefore reasonable that the caudate might be involved when a participant is considering the Market Pricing nature of their relationships, especially ones where they have not previously considered it explicitly.

Although we said we would generally ignore deactivations, one exception will be made because it involves a planned contrast in an ROI. For the Market Pricing > Others contrast, the left caudate ROI was significant in the reverse direction, mirroring the results in the whole-brain analysis. This observation supports the view that Market Pricing involves the affectively coded decision-making routines currently attracting interest in the neuroeconomics field. It is not clear how to interpret the direction of the effect (less active for MP). Additionally, significant relative activations (decreased deactivations) were seen in the bilateral extrastriate cortex. One possible account, other than perceptual confounds, is that market pricing cost-benefit analysis is likely to be mediated emotionally and it is known that affective systems exert a top-down influence on the extrastriate cortex (Bradley et al., 2003). At any rate, further research is required before conclusions can be formed to avoid making an error of reverse inference.

There were also many effects for the Others > MP contrast, which again may just reflect their involvement in other relational models.

Limitations: A limitation to the present study is that there was only time for two questions for each of the four relational models. Although it would have been possible to ask more questions, time limitations would necessarily have required reducing the number of acquaintances/friends/relatives to be rated. It was judged more important to have a wide range of acquaintances/friends/relatives than to have a wide range of questions and that keeping the task simple would help the participants maintain the desired cognitive mindset. Follow-up studies can probe additional questions and perhaps even help with scale development.

Another issue is that while there is currently some discussion regarding clusterwise statistics (Eklund, Nichols, & Knutsson, 2016), we consider the rebuttal to be persuasive (Slotnick, 2017b; Slotnick, 2017a). In any case, this critique was not directed at one-sample t-tests nor surface-based analyses and so is irrelevant to the present paper. Indeed, it has been suggested (Cox, Chen, Glen, Reynolds, & Taylor, 2017, p. 161) that restricting analyses to the gray matter, which is what a surface-based analysis does, may be a solution to the concern about the clusterwise statistic, assuming that the problem does exist. The subcortical region does use a volume-based analysis, so if further exploration of this topic reveals the need for more stringency, then readers may apply a more conservative p-value threshold as needed.

Another limitation is that because of the technical difficulties with the E-Prime script, behavioral data were only obtained for a quarter of the participants. It was therefore not possible to perform trial-by-trial analyses. While unfortunate, it did not impact the ability to perform the intended boxcar analyses, which yield more robust hemodynamic responses than event-related designs (Huettel et al., 2004). It is well-established that top-down manipulations that focus attention on a task dimension can cause the neural substrates to be more active (e.g., Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1991; Harter & Aine, 1984; Lux et al., 2004; Ranganath, DeGutis, & D'Esposito, 2004; Woodruff et al., 1996). Furthermore, a trial-based analysis that utilized the behavioral responses as a covariate would focus the analysis on the trial-level decision processes (e.g., agree-disagree) rather than the task processes (e.g., how similar is the target person?). Investigations involving manipulation of task set do not require trial-by-trial ratings to be successful, although clearly the additional information could have been helpful for examining stimulus-related issues.

Conclusions

At any rate, these neuroimaging findings help advance the literature by helping support the hypothesis that the four relational models can be treated as separable cultural dimensions as they were associated with different activation patterns and the findings support the neural model of the RMT advanced in this paper for the first time. The activation regions also provided some clues for further theory development of the relational models. Furthermore, the pattern of data was overall not consistent with the assertion that the relational models are arranged as a cumulative hierarchy. Ultimately, neuroimaging data may prove a useful tool for refining the RMT measures, both by improving the conceptual underpinnings (while being mindful of the risks of reverse inference) as well as by providing a direct test of whether a given scale activates the appropriate neural regions.

Acknowledgements

This work was supported by DoD funding. Thanks to Alex Smaliy and Tommy Fiske for their invaluable assistance. Thanks to Joan Chiao for her helpful comments on a preliminary version of this manuscript. Thanks to Alan Fiske for his work as a consultant. Molly Barnes also contributed to this work and qualifies as the second author, but we have lost touch with her and have been unable to obtain her permission to be listed as an author on this work.

Footnotes

1) While we do think that an admiral's order will carry more weight than that of a lieutenant, we suggest that this is due to admixture by other confounded relational models. For example, in the West the military is normally perceived to be a meritocracy so an admiral will also be more admired than a lieutenant and thus elicit more of a desire to win respect in return. An admiral that is in some disrepute but nonetheless must be obeyed might be a better AR comparison with a lieutenant. Perhaps there is also an element of EM in the sense of not wanting to incur personal disfavor with a powerful individual. Further specifying that the authority situation involves anonymity for the midshipman would further unconfound matters. In a different culture (perhaps one characterized by nepotism and weak central command) an admiral might very well not carry more weight than that of a lieutenant.

References

Adams, R. B., Gordon, H. L., Baird, A. A., Ambady, N., & Kleck, R. E. (2003). Effects of gaze on amygdala sensitivity to anger and fear faces. *Science*, *300*, 1536.

Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2004). Inhibition and the right inferior frontal cortex. *Trends Cogn Sci*, *8*(4), 170-177.

Arsalidou, M., & Taylor, M. J. (2011). Is 2+ 2= 4? Meta-analyses of brain areas needed for numbers and calculations. *Neuroimage*, *54*(3), 2382-2393.

Ashby, F. G., Alfonso-Reese, L. A., Turken, A. U., & Waldron, E. M. (1998). A neuropsychological theory of multiple systems in category learning. *Psychol Rev*, *105*(3), 442-481.

Avenanti, A., Sirigu, A., & Aglioti, S. M. (2010). Racial bias reduces empathic sensorimotor resonance with other-race pain. *Curr Biol*, *20*(11), 1018-1022.

Azevedo, R. T., Macaluso, E., Avenanti, A., Santangelo, V., Cazzato, V., & Aglioti, S. M. (2013). Their pain is not our pain: brain and autonomic correlates of empathic resonance with the pain of same and different race individuals. *Hum Brain Mapp*, *34*(12), 3168-3181.

Bernhardt, B. C., & Singer, T. (2012). The neural basis of empathy. *Annu Rev Neurosci*, *35*, 1-23.

Boorman, E. D., Rushworth, M. F., & Behrens, T. E. (2013). Ventromedial prefrontal and anterior cingulate cortex adopt choice and default reference frames during sequential multi-alternative choice. *J Neurosci*, *33*(6), 2242-2253.

Bradley, M. M., Sabatinelli, D., Lang, P. J., Fitzsimmons, J. R., King, W., & Desai, P. (2003). Activation of the visual cortex in motivated attention. *Behav Neurosci*, *117*(2), 369-380.

Brannon, E. M. (2006). The representation of numerical magnitude. *Curr Opin Neurobiol*, *16*(2), 222-229.

Burke, C. J., Brunger, C., Kahnt, T., Park, S. Q., & Tobler, P. N. (2013). Neural integration of risk and effort costs by the frontal pole: only upon request. *J Neurosci*, *33*(4), 1706-13a.

Cappelletti, M., Lee, H. L., Freeman, E. D., & Price, C. J. (2010). The role of right and left parietal lobes in the conceptual processing of numbers. *Journal of cognitive neuroscience*, *22*(2), 331-346.

Carpenter, K. L., Wills, A. J., Benattayallah, A., & Milton, F. (2016). A Comparison of the neural correlates that underlie rule-based and information-integration category learning. *Hum Brain Mapp*.

Chiao, J. Y., Harada, T., Oby, E. R., Li, Z., Parrish, T., & Bridge, D. J. (2009). Neural representations of social status hierarchy in human inferior parietal cortex. *Neuropsychologia*, *47*(2), 354-363.

Chiao, J. Y., Hariri, A. R., Harada, T., Mano, Y., Sadato, N., Parrish, T. B., & Iidaka, T. (2010). Theory and methods in cultural neuroscience. *Social cognitive and affective neuroscience*, *5*(2-3), 356-361.

Cloutier, J., Ambady, N., Meagher, T., & Gabrieli, J. D. (2012). The neural substrates of person perception: spontaneous use of financial and moral status knowledge. *Neuropsychologia*, *50*(9), 2371-2376.

Corbetta, M., Miezin, F. M., Dobmeyer, S., Shulman, G. L., & Petersen, S. E. (1991). Selective and divided attention during visual discriminations of shape, color, and speed: Functional anatomy by positron emission tomography. *Journal of Neuroscience*, *11*(8), 2383-2402.

Cox, R. W., Chen, G., Glen, D. R., Reynolds, R. C., & Taylor, P. A. (2017). FMRI Clustering in AFNI: False-Positive Rates Redux. *Brain Connect*, *7*(3), 152-171.

Croxson, P. L., Walton, M. E., O'Reilly, J. X., Behrens, T. E., & Rushworth, M. F. (2009). Effort-based cost-benefit valuation and the human brain. *J Neurosci*, *29*(14), 4531-4541.

Dambacher, F., Sack, A. T., Lobbestael, J., Arntz, A., Brugmann, S., & Schuhmann, T. (2014). The role of right prefrontal and medial cortex in response inhibition: interfering with action restraint and action cancellation using transcranial magnetic brain stimulation. *J Cogn Neurosci*, *26*(8), 1775-1784.

Dehaene, S. (1994). Dissociable mechanisms of subitizing and counting: Neuropsychological evidence from simultanagnosis patients. *Journal of Experimental Psychology: Human Perception & Performance*, *20*(5), 958-975.

Dehaene, S., Dehaene-Lambertz, G., & Cohen, L. (1998). Abstract representations of numbers in the animal and human brain. *Trends in neurosciences*, *21*(8), 355-361.

Delgado, M. R., Frank, R. H., & Phelps, E. A. (2005). Perceptions of moral character modulate the neural systems of reward during the trust game. *Nat Neurosci*, *8*(11), 1611-1618.

Desikan, R. S., Segonne, F., Fischl, B., Quinn, B. T., Dickerson, B. C., Blacker, D., Buckner, R. L., Dale, A. M., Maguire, R. P., Hyman, B. T., Albert, M. S., & Killiany, R. J. (2006). An automated labeling system for subdividing the human cerebral cortex on MRI scans into gyral based regions of interest. *Neuroimage*, *31*(3), 968-980.

Diekhof, E. K., Kaps, L., Falkai, P., & Gruber, O. (2012). The role of the human ventral striatum and the medial orbitofrontal cortex in the representation of reward magnitude - an activation likelihood estimation meta-analysis of neuroimaging studies of passive reward expectancy and outcome processing. *Neuropsychologia*, *50*(7), 1252-1266.

Dien, J., Blok, S., & Glazer, S. (2011). *Cultural priming: Adopting the adversary's mindset to improve analysis*. College Park, MD: University of Maryland Center for Advanced Study of Language.

Domínguez Duque, J. F., Turner, R., Lewis, E. D., & Egan, G. (2010). Neuroanthropology: a humanistic science for the study of the culture–brain nexus. *Social cognitive and affective neuroscience*, *5*(2-3), 138-147.

Domínguez Duque, J. F., Turner, R., Lewis, E. D., & Egan, G. (2009). Neuroanthropology: a humanistic science for the study of the culture–brain nexus. *Social Cognitive and Affective Neuroscience*, *5*(2-3), 138-147.

Douglas, M. (1970). *Natural Symbols*. London: Routledge.

Dunlap, W. P., Cortina, J. M., Vaslow, J. B., & Burke, M. J. (1996). Meta-analysis of experiments with matched groups or repeated measures designs. *Psychological Methods*, *1*(2), 170-177.

Eger, E., Sterzer, P., Russ, M. O., Giraud, A. L., & Kleinschmidt, A. (2003). A supramodal number representation in human intraparietal cortex. *Neuron*, *37*(4), 719-726.

Eklund, A., Nichols, T. E., & Knutsson, H. (2016). Cluster failure: Why fMRI inferences for spatial extent have inflated false-positive rates. *Proc Natl Acad Sci U S A*, *113*(28), 7900-7905.

Fan, Y., Duncan, N. W., de Greck, M., & Northoff, G. (2011). Is there a core neural network in empathy? An fMRI based quantitative meta-analysis. *Neurosci Biobehav Rev*, *35*(3), 903-911.

Fareri, D. S., Chang, L. J., & Delgado, M. R. (2012). Effects of direct social experience on trust decisions and neural reward circuitry. *Frontiers in neuroscience*, *6*.

Farrow, T. F., Jones, S. C., Kaylor-Hughes, C. J., Wilkinson, I. D., Woodruff, P. W., Hunter, M. D., & Spence, S. A. (2011). Higher or lower? The functional anatomy of perceived allocentric social hierarchies. *Neuroimage*, *57*(4), 1552-1560.

Fischl, B. (2012). FreeSurfer. *Neuroimage*, *62*(2), 774-781.

Fischl, B., Salat, D. H., Busa, E., Albert, M., Dieterich, M., Haselgrove, C., van der Kouwe, A., Killiany, R., Kennedy, D., Klaveness, S., Montillo, A., Makris, N., Rosen, B., & Dale, A. M. (2002). Whole brain segmentation: automated labeling of neuroanatomical structures in the human brain. *Neuron*, *33*(3), 341-355.

Fiske, A. P. (1992). The four elementary forms of sociality: Framework for a unified theory of social relations. *Psychological Review*, *99*(4), 689-723.

Fiske, A. P. (2004). Relational models theory 2.0. In N. Haslam (Ed.), *Relational models theory: A contemporary overview* (pp. 3-25). Mahwah, NJ: Lawrence Erlbaum Associates.

Fiske, A. P., & Haslam, N. (2005). The four basic social bonds. In M. W. Baldwin (Ed.), *Interpersonal Cognition* (pp. 267-298). New York, NY: Guilford Press.

Fiske, A. P. (2002). Socio-moral emotions motivate action to sustain relationships. *Self and Identity*, *1*(2), 169-175.

Fouragnan, E., Chierchia, G., Greiner, S., Neveu, R., Avesani, P., & Coricelli, G. (2013). Reputational priors magnify striatal responses to violations of trust. *J Neurosci*, *33*(8), 3602-3611.

Friston, K. J., Zarahn, E., Josephs, O., Henson, R. N., & Dale, A. M. (1999). Stochastic designs in event-related fMRI. *Neuroimage*, *10*(5), 607-619.

Garcin, B., Volle, E., Dubois, B., & Levy, R. (2012). Similar or different? The role of the ventrolateral prefrontal cortex in similarity detection. *PLoS One*, *7*(3), e34164.

Giora, R. (1997). Understanding figurative and literal language: The graded salience hypothesis. *Cognitive Linguistics*, *8*(3), 183-206.

Göbel, S., Walsh, V., & Rushworth, M. F. (2001). The mental number line and the human angular gyrus. *Neuroimage*, *14*(6), 1278-1289.

Goldberg, G. (1985). Supplementary motor area structure and function: Review and hypotheses. *Behavioral and Brain Sciences*, *8*, 567-616.

Grabenhorst, F., & Rolls, E. T. (2011). Value, pleasure and choice in the ventral prefrontal cortex. *Trends Cogn Sci*, *15*(2), 56-67.

Greenfield, P. M. (1991). Language, tools, and brain: The ontogeny and phylogeny of hierarchically organized sequential behavior. *Behavioral and Brain Sciences*, *14*(4), 531-595.

Han, S. (2010). Cultural neuroscience approach to understanding of self. State of the art presentation. *XXth International Congress of Cross-Cultural Psychology*.

Hanakawa, T. (2011). Rostral premotor cortex as a gateway between motor and cognitive networks. *Neurosci Res*, *70*(2), 144-154.

Harter, M. R., & Aine, C. J. (1984). Brain mechanisms of visual selective attention. In R. Parasuraman & D. R. Davies (Eds.), *Varieties of attention* (pp. 293-321). New York:

Academic Press.

Haslam, N. (1995). Factor structure of social relationships: An examination of relational models and resource exchange theories. *Journal of Social and Personal Relationships*, *12*(2), 217-227.

Haslam, N., & Fiske, A. P. (1999). Relational models theory: A confirmatory factor analysis. *Personal Relationships*, *6*(2), 241-250.

Heinke, M. S., & Louis, W. R. (2009). Cultural background and individualistic–collectivistic values in relation to similarity, perspective taking, and empathy. *Journal of Applied Social Psychology*, *39*(11), 2570-2590.

Houston, D. A. (1990). Empathy and the self: Cognitive and emotional influences on the evaluation of negative affect in others. *Journal of Personality and Social Psychology*, *59*(5), 859.

Huang, S., & Han, S. (2014). Shared beliefs enhance shared feelings: religious/irreligious identifications modulate empathic neural responses. *Soc Neurosci*, *9*(6), 639-649.

Huettel, S. A., Song, A. W., & McCarthy, G. (2004). *Functional magnetic resonance imaging*. Sunderland, Massachusetts: Sinauer Associates.

Iacoboni, M., Lieberman, M. D., Knowlton, B. J., Molnar-Szakacs, I., Moritz, M., Throop, C. J., & Fiske, A. P. (2004). Watching social interactions produces dorsomedial prefrontal and medial parietal BOLD fMRI signal increases compared to a resting baseline. *Neuroimage*, *21*(3), 1167-1173.

Kable, J. W., & Glimcher, P. W. (2009). The neurobiology of decision: consensus and controversy. *Neuron*, *63*(6), 733-745.

Kadosh, R. C., & Walsh, V. (2009). Numerical representation in the parietal lobes: Abstract or not abstract? *Behavioral and Brain Sciences*, *32*(3), 313.

Kahnt, T., & Tobler, P. N. (2013). Salience signals in the right temporoparietal junction facilitate value-based decisions. *J Neurosci*, *33*(3), 863-869.

Kansaku, K., Carver, B., Johnson, A., Matsuda, K., Sadato, N., & Hallett, M. (2007). The role of the human ventral premotor cortex in counting successive stimuli. *Experimental brain research*, *178*(3), 339-350.

King-Casas, B., Tomlin, D., Anen, C., Camerer, C. F., Quartz, S. R., & Montague, P. R. (2005). Getting to know you: reputation and trust in a two-person economic exchange. *Science*, *308*(5718), 78-83.

Kitayama, S., & Park, J. (2010). Cultural neuroscience of the self: understanding the social grounding of the brain. *Social cognitive and affective neuroscience*, *5*(2-3), 111-129.

Knutson, B., Rick, S., Wimmer, G. E., Prelec, D., & Loewenstein, G. (2007). Neural predictors of purchases. *Neuron*, *53*(1), 147-156.

Koenig, P., Smith, E. E., Glosser, G., DeVita, C., Moore, P., McMillan, C., Gee, J., & Grossman, M. (2005). The neural basis for novel semantic categorization. *Neuroimage*, *24*(2), 369-383.

Krienen, F. M., Tu, P. C., & Buckner, R. L. (2010). Clan mentality: evidence that the medial prefrontal cortex responds to close others. *The Journal of Neuroscience*, *30*(41), 13906-13915.

Kurniawan, I. T., Guitart-Masip, M., Dayan, P., & Dolan, R. J. (2013). Effort and valuation in the brain: the effects of anticipation and execution. *J Neurosci*, *33*(14), 6160-6169.

Laird, A. R., Robinson, J. L., McMillan, K. M., Tordesillas-Gutierrez, D., Moran, S. T., Gonzales, S. M., Ray, K. L., Franklin, C., Glahn, D. C., Fox, P. T., & Lancaster, J. L. (2010). Comparison of the disparity between Talairach and MNI coordinates in functional neuroimaging data: validation of the Lancaster transform. *Neuroimage*, *51*(2), 677-683.

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Front Psychol*, *4*, 863.

Lamm, C., Meltzoff, A. N., & Decety, J. (2010). How do we empathize with someone who is not like us? A functional magnetic resonance imaging study. *J Cogn Neurosci*, *22*(2), 362-376.

Lamm, C., Decety, J., & Singer, T. (2011). Meta-analytic evidence for common and distinct neural networks associated with directly experienced pain and empathy for pain. *Neuroimage*, *54*(3), 2492-2502.

Lancaster, J. L., Rainey, L. H., Summerlin, J. L., Freitas, C. S., Fox, P. T., Evans, A. C., Toga, A. W., & Mazziotta, J. C. (1997). Automated labeling of the human brain: a preliminary report on the development and evaluation of a forward-transform method. *Human brain mapping*, *5*(4), 238.

Lancaster, J. L., Tordesillas-Gutierrez, D., Martinez, M., Salinas, F., Evans, A., Zilles, K., Mazziotta, J. C., & Fox, P. T. (2007). Bias between MNI and Talairach coordinates analyzed using the ICBM-152 brain template. *Hum Brain Mapp*, *28*(11), 1194-1205.

Lende, D. H., & Downey, G. (2012). Neuroanthropology and its applications: an introduction. *Annals of Anthropological Practice*, *36*(1), 1-25.

Lewin, K. (1939). Field theory and experiment in social psychology: Concepts and methods. *American journal of sociology*, *44*(6), 868-896.

Liu, X., Hairston, J., Schrier, M., & Fan, J. (2011). Common and distinct networks underlying reward valence and processing stages: a meta-analysis of functional neuroimaging studies. *Neurosci Biobehav Rev*, *35*(5), 1219-1236.

Lux, S., Marshall, J. C., Ritzl, A., Weiss, P. H., Pietrzyk, U., Shah, N. J., Zilles, K., & Fink, G. R. (2004). A functional magnetic resonance imaging study of local/global processing with stimulus presentation in the peripheral visual hemifields. *Neuroscience*, *124*(1), 113-120.

Marsh, A. A., Blair, K. S., Jones, M. M., Soliman, N., & Blair, R. J. (2009). Dominance and submission: the ventrolateral prefrontal cortex and responses to status cues. *J Cogn Neurosci*, *21*(4), 713-724.

Mashal, N., Faust, M., Hendler, T., & Jung-Beeman, M. (2007). An fMRI investigation of the neural correlates underlying the processing of novel metaphoric expressions. *Brain Lang*, *100*(2), 115-126.

Mason, M., Magee, J. C., & Fiske, S. T. (2014). Neural substrates of social status inference: roles of medial prefrontal cortex and superior temporal sulcus. *J Cogn Neurosci*, *26*(5), 1131-1140.

Milgram, S. (1974). *Obedience to Authority: An Experimental View*. Taylor & Francis.

Milton, F., & Pothos, E. M. (2011). Category structure and the two learning systems of COVIS. *Eur J Neurosci*, *34*(8), 1326-1336.

Milton, F., Wills, A. J., & Hodgson, T. L. (2009). The neural basis of overall similarity and single-dimension sorting. *Neuroimage*, *46*(1), 319-326.

Mitchell, J. P., Banaji, M. R., & MacRae, C. N. (2005). The link between social cognition and self-referential thought in the medial prefrontal cortex. *Journal of cognitive neuroscience*, *17*(8), 1306-1315.

Mitchell, J. P., Macrae, C. N., & Banaji, M. R. (2006). Dissociable medial prefrontal contributions to judgments of similar and dissimilar others. *Neuron*, *50*(4), 655-663.

Mobbs, D., Yu, R., Meyer, M., Passamonti, L., Seymour, B., Calder, A. J., Schweizer, S., Frith, C. D., & Dalgleish, T. (2009). A key role for similarity in vicarious reward. *Science*, *324*(5929), 900.

Molenberghs, P. (2013). The neuroscience of in-group bias. *Neurosci Biobehav Rev*, *37*(8), 1530-1536.

Muscatell, K. A., Morelli, S. A., Falk, E. B., Way, B. M., Pfeifer, J. H., Galinsky, A. D., Lieberman, M. D., Dapretto, M., & Eisenberger, N. I. (2012). Social status modulates neural activity in the mentalizing network. *Neuroimage*, *60*(3), 1771-1777.

Nelson, D. W., & Baumgarte, R. (2004). Cross‐Cultural Misunderstandings Reduce Empathic Responding1. *Journal of Applied Social Psychology*, *34*(2), 391-401.

Nelson, D. W., Klein, C. T. F., & Irvin, J. E. (2003). Motivational antecedents of empathy: Inhibiting effects of fatigue. *Basic and Applied Social Psychology*, *25*(1), 37-50.

Nieder, A. (2005). Counting on neurons: the neurobiology of numerical competence. *Nature*

Reviews Neuroscience, *6*(3), 177-190.

Nieder, A., Diester, I., & Tudusciuc, O. (2006). Temporal and spatial enumeration processes in the primate parietal cortex. *Science*, *313*(5792), 1431-1435.

Nomura, E. M., Maddox, W. T., Filoteo, J. V., Ing, A. D., Gitelman, D. R., Parrish, T. B., Mesulam, M. M., & Reber, P. J. (2007). Neural correlates of rule-based and information-integration visual category learning. *Cereb Cortex*, *17*(1), 37-43.

Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*, *9*(1), 97-113.

Pariyadath, V., Plitt, M. H., Churchill, S. J., & Eagleman, D. M. (2012). Why overlearned sequences are special: distinct neural networks for ordinal sequences. *Front Hum Neurosci*, *6*, 328.

Park, S. Q., Kahnt, T., Rieskamp, J., & Heekeren, H. R. (2011). Neurobiology of value integration: when value impacts valuation. *J Neurosci*, *31*(25), 9307-9314.

Passingham, R. (1993). *The frontal lobes and voluntary action* (21). Oxford: Oxford University Press.

Picard, N., & Strick, P. L. (2001). Imaging the premotor areas. *Curr Opin Neurobiol*, *11*(6), 663-672.

Pinel, P., Dehaene, S., Riviere, D., & LeBihan, D. (2001). Modulation of parietal activation by semantic distance in a number comparison task. *Neuroimage*, *14*(5), 1013-1026.

Poldrack, R. A. (2011). Inferring mental states from neuroimaging data: from reverse inference to large-scale decoding. *Neuron*, *72*(5), 692-697.

Prevost, C., Pessiglione, M., Metereau, E., Clery-Melin, M. L., & Dreher, J. C. (2010). Separate valuation subsystems for delay and effort decision costs. *J Neurosci*, *30*(42), 14080-14090.

Rai, T. S., & Fiske, A. P. (2011). Moral psychology is relationship regulation: moral motives for unity, hierarchy, equality, and proportionality. *Psychol Rev*, *118*(1), 57-75.

Ranganath, C., DeGutis, J., & D'Esposito, M. (2004). Category-specific modulation of inferior temporal activity during working memory encoding and maintenance. *Brain Res Cogn Brain Res*, *20*(1), 37-45.

Rizzolatti, G., Fogassi, L., & Gallese, V. (2002). Motor and cognitive functions of the ventral premotor cortex. *Curr Opin Neurobiol*, *12*(2), 149-154.

Rizzolatti, G., & Sinigaglia, C. (2010). The functional role of the parieto-frontal mirror circuit: interpretations and misinterpretations. *Nat Rev Neurosci*, *11*(4), 264-274.

Roland, P. E., Skinhoj, E., Lassen, N. A., & Larsen, B. (1980). Different areas in man in organization of voluntary movements in extrapersonal spaces. *Journal of Neurophysiology*, *43*, 137-150.

Rushworth, M. F., Noonan, M. P., Boorman, E. D., Walton, M. E., & Behrens, T. E. (2011). Frontal cortex and reward-guided learning and decision-making. *Neuron*, *70*(6), 1054-1069.

Sanfey, A. G., & Chang, L. J. (2008). Multiple systems in decision making. *Ann N Y Acad Sci*, *1128*, 53-62.

Santens, S., Roggeman, C., Fias, W., & Verguts, T. (2010). Number processing pathways in human parietal cortex. *Cerebral Cortex*, *20*(1), 77-88.

Schmitz, C. (2012). *LimeSurvey: An Open Source survey tool*. Hamburg, Germany: LimeSurvey Project. Retrieved from http://www.limesurvey.org

Sebanz, N., Rebbechi, D., Knoblich, G., Prinz, W., & Frith, C. D. (2007). Is it really my turn? An event-related fMRI study of task sharing. *Soc Neurosci*, *2*(2), 81-95.

Seitz, R. J., Nickel, J., & Azari, N. P. (2006). Functional modularity of the medial prefrontal cortex: involvement in human empathy. *Neuropsychology*, *20*(6), 743-751.

Shkurko, A. V. (2012). Is social categorization based on relational ingroup/outgroup opposition? A meta-analysis. *Soc Cogn Affect Neurosci*.

Slotnick, S. D. (2017a). Cluster success: fMRI inferences for spatial extent have acceptable false-positive rates. *Cogn Neurosci*, 1-6.

Slotnick, S. D. (2017b). Resting-state fMRI data reflects default network activity rather than null data: A defense of commonly employed methods to correct for multiple comparisons. *Cogn Neurosci*, 1-3.

Squire, L. R. (1992). Declarative and nondeclarative memory: Multiple brain systems supporting learning and memory. *Journal of Cognitive Neuroscience*, *4*(3), 232-243.

Stanley, D. A., Sokol-Hessner, P., Fareri, D. S., Perino, M. T., Delgado, M. R., Banaji, M. R., & Phelps, E. A. (2012). Race and reputation: perceived racial group trustworthiness influences the neural correlates of trust decisions. *Philos Trans R Soc Lond B Biol Sci*, *367*(1589), 744-753.

Stevens, S. S. (1946). On the theory of scales of measurement. *Science*, *103*(2684), 677-680.

Talairach, J., & Tournoux, P. (1988). *A co-planar stereotaxic atlas of a human brain*. Stuttgart: Thieme.

Talmi, D., Dayan, P., Kiebel, S. J., Frith, C. D., & Dolan, R. J. (2009). How humans integrate the prospects of pain and reward during choice. *J Neurosci*, *29*(46), 14617-14626.

Van Overwalle, F. (2009). Social cognition and the brain: a meta-analysis. *Hum Brain Mapp*, *30*(3), 829-858.

Van Overwalle, F., & Baetens, K. (2009). Understanding others' actions and goals by mirror and mentalizing systems: a meta-analysis. *Neuroimage*, *48*(3), 564-584.

Van Overwalle, F., Baetens, K., Mariën, P., & Vandekerckhove, M. (2014). Social cognition and the cerebellum: a meta-analysis of over 350 fMRI studies. *Neuroimage*, *86*, 554-572.

Van Overwalle, F. (2011). A dissociation between social mentalizing and general reasoning. *Neuroimage*, *54*(2), 1589-1599.

Verweij, M., Senior, T. J., Domínguez D, J. F., & Turner, R. (2015). Emotion, rationality, and decision-making: how to link affective and social neuroscience with social theory. *Front Neurosci*, *9*, 332.

Vilberg, K. L., & Rugg, M. D. (2008). Memory retrieval and the parietal cortex: A review of evidence from a dual-process perspective. *Neuropsychologia*.

von Helversen, B., Karlsson, L., Rasch, B., & Rieskamp, J. (2014). Neural substrates of similarity and rule-based strategies in judgment. *Front Hum Neurosci*, *8*, 809.

Wardle, M. C., Fitzgerald, D. A., Angstadt, M., Sripada, C. S., McCabe, K., & Phan, K. L. (2013). The caudate signals bad reputation during trust decisions. *PLoS One*, *8*(6), e68884.

Woodruff, P. W. R., Benson, R. R., Bandettini, P. A., Kwong, K. K., Howard, R. J., Talavage, T., Belliveau, J., & Rosen, B. R. (1996). Modulation of auditory and visual cortex by selective attention is modality-dependent. *Neuroreport*, *7*(12), 1909-1913.

Yamakawa, Y., Kanai, R., Matsumura, M., & Naito, E. (2009). Social distance evaluation in human parietal cortex. *PLoS One*, *4*(2), e4360.

Zhang, M., Gao, X., Li, B., Yu, S., Gong, T., Jiang, T., Hu, Q., & Chen, Y. (2016). Spatial Representation of Ordinal Information. *Front Psychol*, *7*, 505.

Zink, C. F., Tong, Y., Chen, Q., Bassett, D. S., Stein, J. L., & Meyer-Lindenberg, A. (2008). Know your place: neural processing of social hierarchy in humans. *Neuron*, *58*(2), 273-283.

Figure Legends

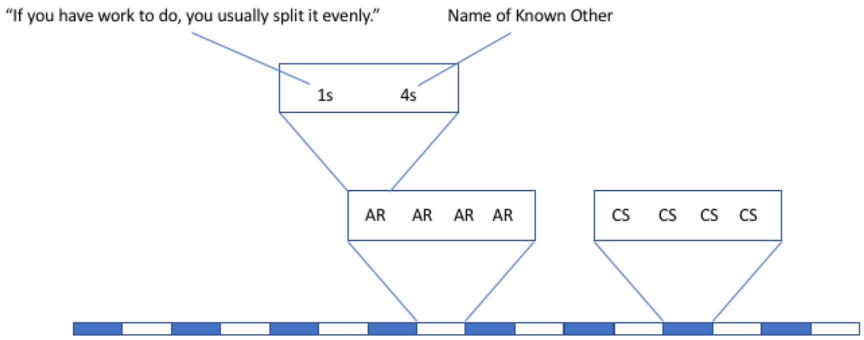


Figure 1: Experimental Design.

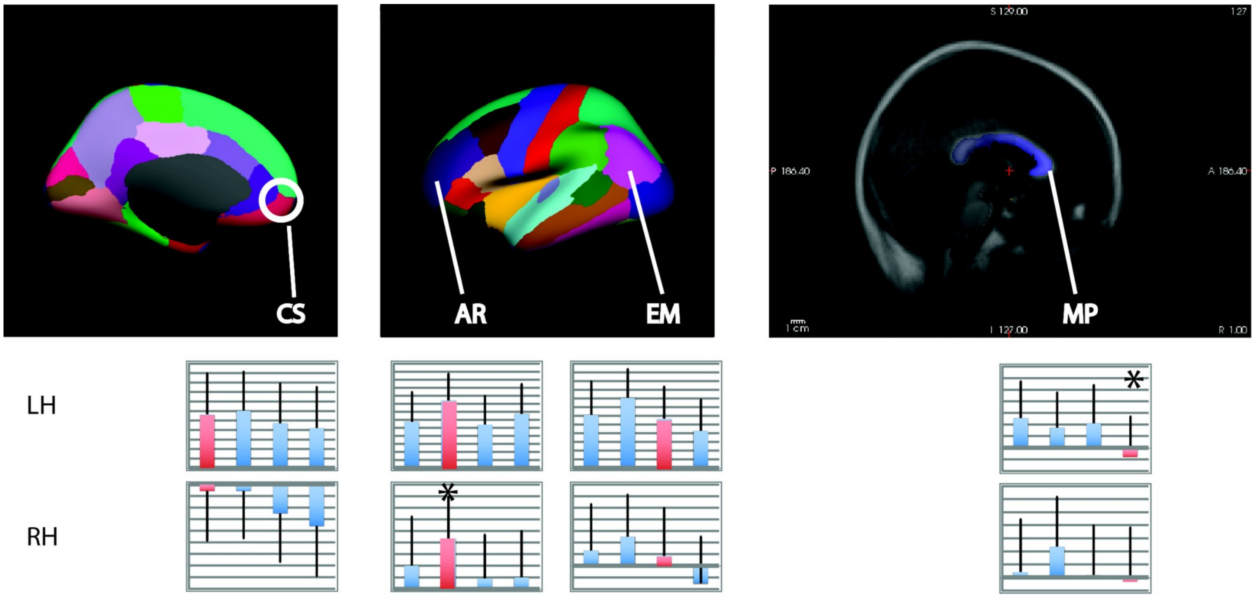
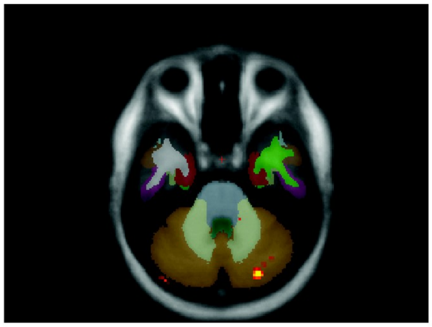
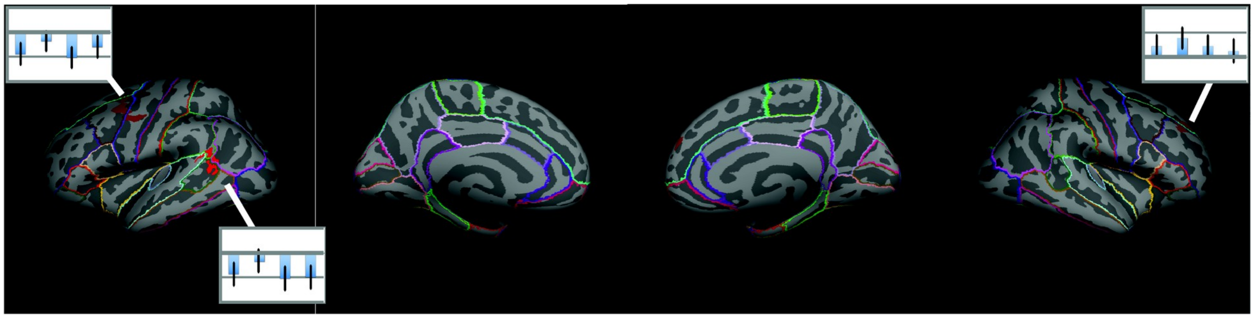


Figure 2: Regions of Interest. The four regions of interests are delineated herein, one for each relational model. The cortical parcellation is based on the Desikan-Killiany Atlas. CS= rostral anterior cingulate. AR= rostral middle frontal. EM= inferior parietal. MP=caudate. Bars indicate percent signal change (each grid line is .01%, so a bar that reaches just the first grid line is a .01% effect) with standard errors, for the four main conditions (CS, AR, EM, and MP, so for each figure the first bar is CS, the second bar is AR, the third bar is EM, and the fourth bar is MP). The bar with the planned contrast is marked in a different color. The asterisks mark the bar with the significant planned contrast. Bars corresponding to non-planned contrasts were not tested.

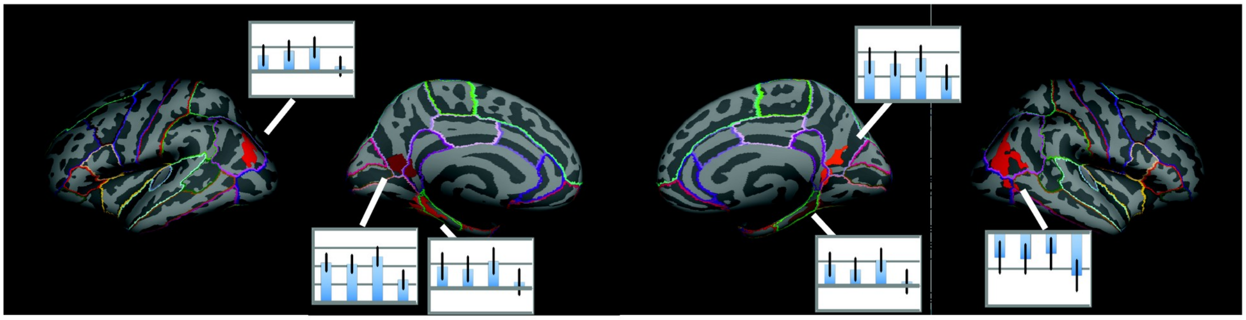
CS vs Others



AR vs Others



EM vs Others



MP vs Others

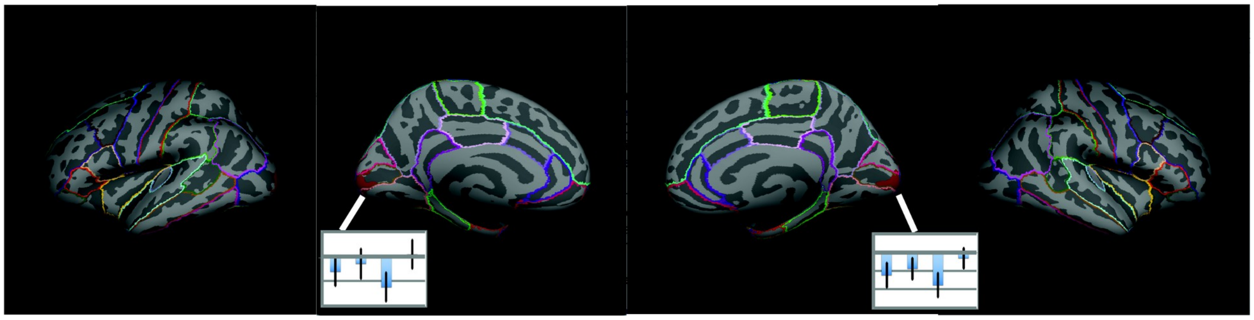


Figure 3: Main Effect Activations. Significant clusters from whole-brain analysis (cortical surface results and activations only). Colors demark distinct clusters but otherwise have no meaning. Bars indicate percent signal change (each grid line is .1%, so a bar that reaches just the first grid line is a .1% effect) with standard errors, for the four main conditions (CS, AR, EM, and MP, so for each figure the first bar is CS, the second bar is AR, the third bar is EM, and the fourth bar is MP). Signal change information is not available for CS vs Others due to software limitations. The cortical parcellation is based on the Desikan-Killiany Atlas. The voxelwise statistical threshold was set at .01 and the clusterwise statistical threshold was set at .05. The bar with the significantly greater effect is marked in a different color.