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RESEARCH ESSAY

HOW TO CONDUCT A FUNCTIONAL MAGNETIC RESONANCE (FMRI) STUDY IN SOCIAL SCIENCE RESEARCH[1]

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Appendix A

Glossary

Term	Explanation
Arteries	Blood vessels that carry oxygenated blood from the heart to the rest of the body.
Axial	A horizontal view of the brain (along the x–y plane in MRI)
B_0	The strong static magnetic field generated by an MRI scanner.
Basis functions	A set of functions whose linear combination can take on a wide range of functional forms. In fMRI analyses, researchers often replace a single hemodynamic response function with basis functions, to improve the flexibility of their design matrices.
Between-subjects	A manipulation in which different conditions are assigned to different subject groups.
Block	A time interval that contains trials from one condition.
Blocked design	The separation of experimental conditions into distinct blocks, so that each condition is presented for an extended period of time.
Blood-oxygenation-level-dependent (BOLD) contrast	The difference in signal on T_2*-weighted images as a function of the amount of deoxygenated hemoglobin.
Bonferroni correction	A stringent form of family-wise error rate correction for multiple comparisons in which the alpha value is decreased proportionally to the number of independent statistical tests.
Brodmann areas	Divisions of the brain based on the influential cyto-architectonic criteria initially proposed by Korbinian Brodmann.
Central nervous system (CNS)	The system composed by the brain and the spinal cord.
Cerebrospinal fluid (CSF)	A colorless liquid that surrounds the brain and spinal cord and fills the ventricles within the brain.
Consent form	An abstract concept that explains behavior but which itself is not directly observable. Attention is an example of a psychological construct.
Contrast	(1) The intensity difference between different quantities being measured by an imaging system. It also can refer to the physical quantity being measured (e.g., T_1 contrast). (2) A statistical comparison of the activation evoked by two (or more) experimental conditions, in order to test a research hypothesis.

Term	Explanation
Control block	A time interval that contains trials of the control condition.
Control condition	A condition that provides a standard to which the experimental condition(s) can be compared. Also called the baseline condition or non-task condition.
Converging operations	The use of two or more techniques to provide complementary evidence used to test an experimental hypothesis or scientific theory.
Co-registration	The spatial alignment of two images or image volumes.
Coronal	A frontal view of the brain (along the /x–z/ plane in MRI).
Correlation analysis	A type of statistical test that evaluates the strength of the relation between two variables. For fMRI studies, correlation analyses typically evaluate the correspondence between a predicted hemodynamic response and the observed data.
Deactivations	Decreases in BOLD activation during task blocks compared with non-task blocks.
Deoxygenated Hemoglobin (dHb)	Hemoglobin without attached oxygen; it is paramagnetic.
Design Matrix	In fMRI implementations of the general linear model, the specification of how the model factors change over time.
Diamagnetic	Having the property of a weak repulsion from a magnetic field.
Dorsal	Toward the top of the brain.
Event	A single instance of the experimental manipulation. Also known as a trial.
Event-related design	Presentation of discrete, short-duration events with randomized timing and order.
False Discovery Rate	Statistical method to correct for multiple comparisons in many hypotheses testing.
Field map	An image of the intensity of the magnetic field across space.
Field of view (FOV)	The total extent of an image along a spatial dimension.
Field potentials	Changes in electrical potential over space associated with postsynaptic neuronal activity.
Field strength	The magnitude of the static magnetic field generated by a scanner, typically expressed in units of Tesla.
Flip angle	The change in the precession angle of the net magnetization following excitation.
Frontal lobe	The most anterior lobe of the cerebrum; it is important for executive processing, motor control, memory, and many other functions.
Functional magnetic resonance imaging (fMRI)	A neuroimaging technique that uses standard MRI scanners to investigate changes in brain function over time.
General linear model (GLM)	A class of statistical tests that assume that the experimental data are composed of the linear combination of different model factors,
Gradient coils	Electromagnetic coils that create controlled spatial variation in the strength of the magnetic field.
Hemodynamic response (HDR)	The change in MR signal on T_2 * images following local neuronal activity. The hemodynamic response results from a decrease in the amount of deoxygenated hemoglobin present within a voxel.
Independent components analysis (ICA)	An important class of data-driven analyses that identify stationary sets of voxels whose activations vary together over time and are maximally distinguishable from other sets.
Informed consent	The process in which a potential subject voluntarily agrees to participate in a research study, after learning about the procedures, risks, and benefits of the study.
Institutional Review Board (IRB)	An independent group of individuals who evaluate the ethical practice of research conducted at their institution. Researchers who wish to conduct research with human subjects should generally receive the approval of their local IRB.
Interleaved slice acquisition	The collection of data in an alternating order, so that data are first acquired from the odd-numbered slices and then from the even-numbered slices, to minimize the influence of excitation pulses upon adjacent slices.

Term	Explanation
Interstimulus interval (ISI)	The separation in time between successive stimuli. Usually refers to the time between the end of one stimulus and the onset of the next, with the term "stimulus-onset asynchrony" (SOA) used to define the time between successive onsets.
Intersubject correlations	Functional MRI time courses that are shared by different individuals while performing the same experimental tasks or experiencing the same stimuli.
Jittering	Randomizing the intervals between successive stimulus events over some range.
Magnetic resonance	Absorption of energy from a magnetic field that oscillates at a particular frequency.
MNI space	A commonly used space for normalization of fMRI data; its coordinates are derived from an average of MRI structural images from several hundred individuals.
MR signal	The current measured in a detector coil following excitation and reception.
Neural Correlates	Brain areas activated by a certain construct
Normalization	The transformation of MRI data from an individual subject to match the spatial properties of a standardized image, such as an averaged brain derived from a sample of many individuals.
Parameter matrix	A matrix that describes the relative contributions of each model to the observed data for each voxel.
Peak	The maximal amplitude of the hemodynamic response, occurring typically about 4 to 6 s following a short-duration event.
Pixel	A two-dimensional picture element.
Preprocessing	Computational procedures that are applied to fMRI data following image reconstruction but before statistical analysis. Preprocessing steps are intended to reduce the variability in the data that is not associated with the experimental task, and to prepare the data for statistical testing.
Pulse sequence	A series of changing magnetic field gradients and oscillating electromagnetic fields that allows the MRI scanner to create images sensitive to a particular physical property.
Random-effects analysis	Intersubject analysis that treats the effect of the experimental manipulation as variable across subjects, so that it could have a different effect on different subjects.
Reaction time	The time required for someone to make a simple motor response to the presentation of a visual stimulus. Note that this is distinct from response time, which applies to situations in which someone should choose between two or more possible responses.
Reference volume	A target image volume to which other image volumes are to be aligned.
Region-of-interest (ROI) analyses	Evaluations of hypotheses about the functional properties of brain regions (i.e., aggregated over a pre-determined set of voxels), often chosen to reflect a priori anatomical distinctions within the brain.
Relaxation	A change in net magnetization over time.
Repetition time (TR)	The time interval between successive excitation pulses, usually expressed in seconds.
Response time	The time required for someone to execute a choice between two or more possible responses. Note that this is distinct from reaction time, which applies to situations when only one possible response is present.
Reverse inference	Reasoning from the outcome of a dependent variable to infer the state of an independent variable (or an intervening unobservable variable).
Right-hand rule	A method used to determine the direction of a magnetic moment generated by a moving charge or electrical current. If the fingers of the right hand are curled around the direction of spin, then the magnetic moment will be in the direction indicated by the thumb.
Rigid-body transformation	A spatial transformation that does not change the size or shape of an object; it has three translational parameters and three rotational parameters.
Rostral	Toward the front of the brain.
Sagittal	A side view of the brain (along the /y/–/z/ plane in MRI).
Segmentation	The process of partitioning an image into constituent parts, typically types of tissue (e.g., gray matter, white matter) or topographical divisions (e.g., different structural regions like Brodmann areas).

Term	Explanation
Signal	Meaningful changes in some quantity. For fMRI, an important class of signals includes changes in intensity associated with the BOLD response.
Signal-to-noise ratio (SNR)	The relative strength of a signal compared with other sources of variability in the data.
Slice	A single slab of an imaging volume. The thickness of the slice is defined by the strength of the gradient and the bandwidth of the electromagnetic pulse used to select it.
Slice selection	The combined use of a spatial magnetic field gradient and an electromagnetic pulse to excite spins within a slice.
Small-volume correction	The restriction of analyses to specific regions-of-interest, defined a priori, to reduce the total number of statistical tests and thus allow for a more liberal significance threshold.
Smoothness	The degree to which the time courses of nearby voxels are temporally correlated.
Spatial smoothing	The blurring of fMRI data across adjacent voxels to improve the validity of statistical testing and maximize functional SNR, at a cost of spatial resolution.
Static magnetic field	The strong magnetic field at the center of the MRI scanner whose strength does not change over time. The strength of the static magnetic field is measured in Tesla.
Statistical map (or Statistical parameter map)	In fMRI, the labeling of all voxels within the image according to the outcome of a statistical test.
Stereotaxic space	A precise mapping system (e.g., of the brain) using 3-D coordinates.
Subtraction	In experimental design, the direct comparison of two conditions that are assumed to differ only in one property, the independent variable.
Superposition	A principle of linear systems that states that the total response to a set of inputs is equivalent to the summation of the independent responses to the inputs.
Talairach space	A commonly used space for normalization of fMRI data; its coordinates are based on measurements from a single post-mortem human brain, as published in an atlas by Talairach and Tournoux.
Time course	The change in MR signal over a series of fMRI images.
Time series	A large number of fMRI images collected at different points in time.
Translation	The movement of an object along an axis in space (in the absence of rotation).
Trial	A single instance of the experimental manipulation, such as stimulus presentation.
Ventral	Toward the bottom of the brain.
Volume (brain)	The collection of all images of the brain, consisting of multiple slices and voxels.
Volumetric	Relating to the measurement of volume.
Voxel	A three-dimensional volume element.
Voxel-wise analysis	Evaluation/testing of hypotheses about functional properties of individual voxels (or small clusters of voxels), often throughout the entire brain volume.

Appendix B

Review of Neuroscience Literature Related to Constructs of Interest to the Social Sciences

Construct/Process	Sample Brain Areas*	Key References
Ambiguity	Insular cortex, Parietal cortex	Krain et al. 2006
Anger	Lateral Orbitofrontal cortex	Murphy et al. 2003
Anxiety	Amygdala–prefrontal circuitry, Inferior Frontal gyrus (Brodman Area 45), Ventromedial Prefrontal cortex	Bishop 2007 Etkin and Wager 2007 Mujica-Parodi 2007
Attention	Right Frontal and Parietal cortices and Thalamus	Coull et al. 1998
Automaticity	Frontal and Striatal cortex, Parietal lobe (Deactivation)	Kubler et al. 2006 Poldrack et al. 2005
Calculation	Anterior Cingulate cortex, Prefrontal cortex limbic system (mainly anterior cingulate cortex and amygdala)	Ernst and Paulus 2005 McClure et al. 2004
Cognitive Effort	Dorsolateral prefrontal cortex, Parietal cortex	Linden et al. 2003 Owen et el. 2005
Competition	Inferior parietal cortex, Medial Prefrontal cortex	Decety et al. 2004
Consciousness	Parietal and Dorsal Prefrontal cortex, Striate cortex, Extrastriate cortex	Rees, Kreiman, and Koch 2002 Rees, Wojciulik et al. 2002
Cooperation	Orbitofrontal cortex	Rilling, Gutman et al. 2002
Disgust	Insular cortex	Britton et al. 2006 Lane et al. 1997 Murphy et al. 2003 Phan et al. 2002
Displeasure	Amygdala, Hippocampus, Insular cortex, Superior Temporal gyrus	Britton et al. 2006 Casacchia et al. 2009
Distrust	Amygdala, Insular cortex	Dimoka 2010 Winston et al. 2002
Emotion in Moral Judgment	Medial Prefrontal cortex, Posterior Cingulate, and angular gyrus	Greene et al. 2001
Emotional Processing	Anterior Cingulate cortex, Medial Prefrontal cortex (Emotional Information- dorsal frontomedial cortex)	Damasio 1996 Ferstl et al. 2005 Phan et al. 2002
Envy	Anterior Cingulate cortex	Takahashi et al. 2009
Fear	Amygdala	LeDoux 2003 Murphy et al. 2003 Phan et al. 2002
Flow	Dorsomedial Prefrontal cortex, Medial Parietal cortex	Iacobini et al. 2004 Katayose 2006
Frustration	Right Anterior Insula, Right Ventral Prefrontal cortex	Abler et al. 2005
Habit	Basal Ganglia, Medial Prefrontal cortex, Medial Temporal lobe	Graybiel 2008 Salat et al. 2006
Happiness	Basal Ganglia (Ventral Striatum and Putamen)	Murphy et al. 2003 Phan et al. 2002
Hate	Medial Frontal gyrus, Right Putamen, Bilaterally in Premotor cortex, Frontal Pole and bilateral Medial Insula, Right Insula, Right Premotor cortex , Right Fronto-Medial gyrus	Zeki and Romaya 2008

Construct/Process	Sample Brain Areas*	Key References
Information Processing	Anterior Frontal cortex, Lateral Prefrontal cortex, Medial Orbitofrontal cortex Hippocampus, Amygdala (Emotional Information- Dorsal Frontomedial cortex)	Dimoka and Davis 2008 Elliot et al. 1997 Ferstl et al. 2005
Intentions	Ventrolateral Prefrontal cortex, Brodmann Area 47	Dove et al. 2008 Okuda et al. 1998
Jealousy	Left Prefrontal cortex	Harmon-Jones et al. 2009
Language function	Broca's area	McDermott et al. 2003
Loss	Insular cortex	Paulus and Frank 2003
Love (maternal)	Ventral part of Anterior Cingulate cortex	Bartels and Zeki 2004
Love (overlap of maternal and romantic)	Striatum (Putamen, Globus Pallidus, Caudate Nucleus), Middle Insula and Dorsal Anterior Cingulate cortex	Bartels and Zeki 2004
Love (romantic)	Dentate gyrus/Hippocampus, Hypothalamus, Ventral Tegmental area	Bartels and Zeki 2004
Moral Judgments	Frontopolar cortex (Brodmann Area 10), Posterior Superior Temporal Sulcus	Borg et al. 2006 Moll et al. 2005
Moral Sensitivity	Amygdala, Thalamus, Upper Midbrain, Medial Orbitofrontal cortex, Medial Prefrontal cortex, Superior Temporal Sulcus	Moll et al. 2002
Motor Intentions	Premotor and Parietal cortex	Desmurget et al. 2009 Lau et al. 2007
Multi-Tasking	Fronto-polar cortex (Brodman Area 10)	Dreher et al. 2008
Optimism	Rostral Anterior Cingulate cortex, Amygdala	Sharot et al. 2007
Person Recognition	Left Hippocampus, Left Middle Temporal gyrus, Left Insula, and Bilateral Cerebellum	Paller et al. 2003
Pleasure/Enjoyment	Anterior Cingulate cortex, Putamen, Medial Prefrontal cortex ,Nucleus Accumbens	Klasen et al. 2008 McLean et al. 2009 Sabatinelli et al. 2008
Priming	Parietal cortex, Middle Temporal cortex, Posterior Superior cortex	Naccache and Dehaene 2001 Wible et al. 2006
Rewards and Utility	Anterior Cingulate cortex, Caudate Nucleus, Nucleus Accumbens, Putamen	Bush et al. 2002 Delgado et al. 2005 McClure et al. 2004
Risk	Nucleus Accumbens	Knutson et al. 2001
Sadness	Subcallosal Cingulate cortex	Murphy et al. 2003 Phan et al. 2002
Self-reflection	Medial Prefrontal cortex, Posterior Cingulate	Johnson et al. 2002
Self-regulation of emotion	Amygdala, Dorsolateral Prefrontal cortex, Hypothalamus	Beauregard et al. 2001
Social Cognition	Amygdala, Cingulate cortex, Temporal lobe, Orbitofrontal cortex, Right Somatosensory cortex, Ventromedial Frontal cortex	Adolphs 1999, 2001
Social Cooperation	Amygdala, Orbitofrontal cortex, Dorsolateral Prefrontal cortex	Rilling, Glenn et al. 2007
Spatial Cognition	Hippocampus, Medial Temporal Lobe	Moser et al. 2008 Shrager et al. 2008
Sympathy	Anterior Superior Frontal gyrus, Inferior Frontal gyrus, Temporal pole, Amygdala, Left Central Sulcus, Right Dorsal Premotor cortex, Dorsomedial prefrontal cortex, pre-SMA, and Inferior Parietal lobule	Decety et al. 2004

Construct/Process	Sample Brain Areas*	Key References
Task Intentions	Anterior Cingulate cortex, Medial and Lateral Prefrontal	Haynes et al. 2007 Winterer et al. 2002
Theory of Mind	Anterior Paracingulate cortex, Medial Prefrontal cortex	McCabe et al. 2001
Trust	Anterior Paracingulate cortex, Caudate Nucleus, Putamen	Dimoka 2010 King-Casas et al. 2005
Uncertainty	Orbitofrontal and Parietal cortex	Huettel et al. 2005 Krain et al. 2006
Unfairness	Dorsolateral Prefrontal cortex, Ventrolateral Prefrontal cortex, Superior Temporal Sulcus	Dulebohn et al. 2009
Visual Perception	Dorsal Lateral Geniculate nucleus to the temporal lobe	Pollen 1999
Working Memory	Anterior Cingulate, Dorsolateral Prefrontal cortex, Orbital Cortical cortex	Braver et al. 1997 Callicott et al. 1999 Cohen et al. 1997

*As discussed in the paper in more detail ("Basic Neuroscience Foundations), while it is possible to make a (forward) inference that a specific construct is associated with certain brain areas, caution should be paid when trying to infer a construct based on the existence of activation in certain brain areas (termed reverse inference). Given that the same brain areas are activated in response to several constructs (as clearly noted in Appendix B), such over-interpretation is problematic. For more details on forward and reverse inference, see Lieberman (2007) and Poldrack (2008).

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Appendix C

Example Results

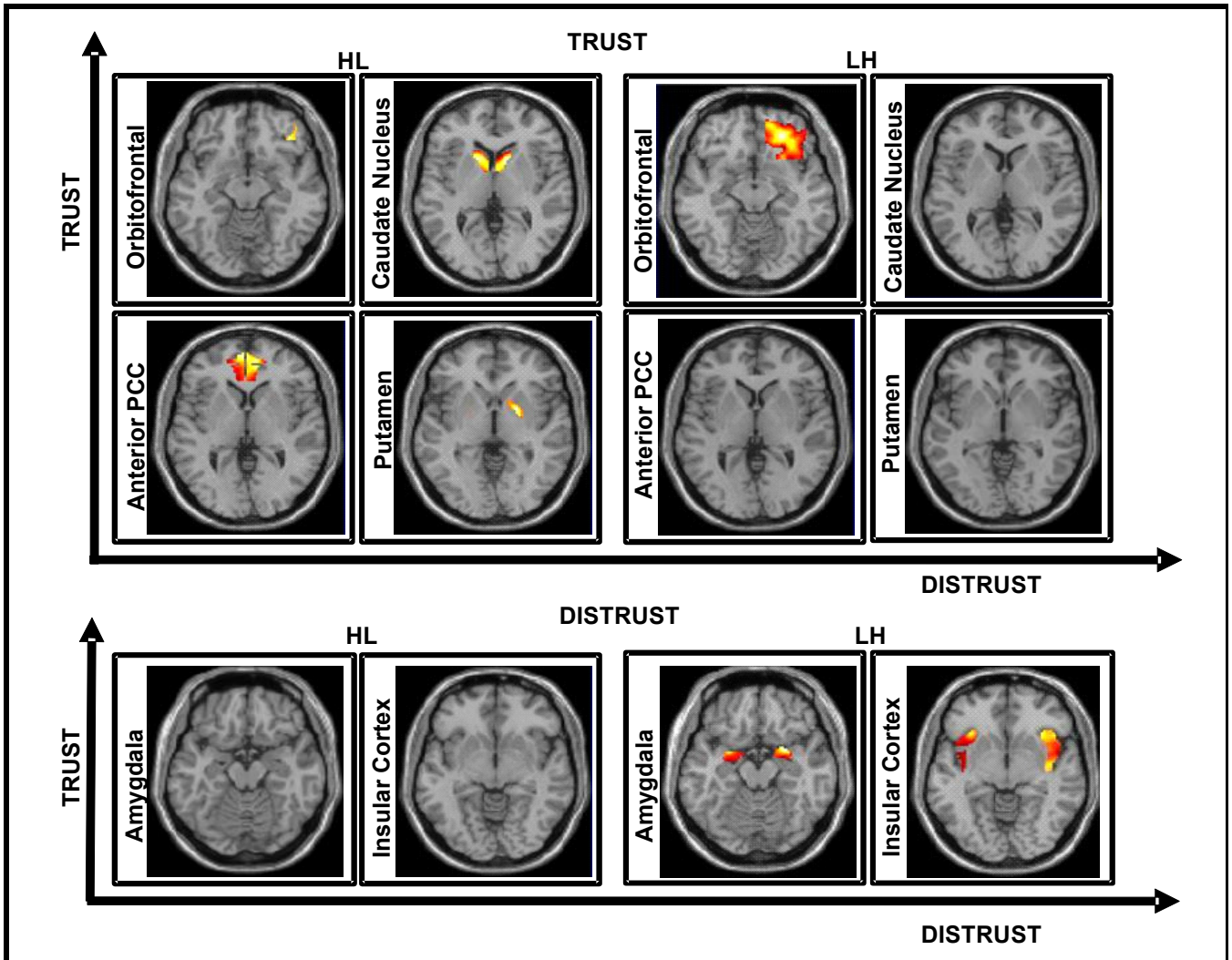

Figure C1. The Neural Correlates of Trust and Distrust (Simplified Version of Figure 3 (p. 386) from Dimoka 2010)

Table C1. Coordinates of Neural Correlates of the Dimensions of Trust and Distrust

Construct	Seller	Brain Area	Coordinates (x,y,z)	Activation (max)
Credibility	High-Trust/Low-Distrust	Caudate Nucleus	Left: -12,18,4 Right: 12,18,4	z = 3.78, p < .01
	High-Trust/Low-Distrust	Putamen	24, 6, 0	z = 3.05, p < .01
	Low-Trust/High-Distrust	Orbitofrontal cortex	26, 44, -12	z = 3.54, p < .01
Benevolence	High-Trust/Low-Distrust	Caudate Nucleus	Left: -8, 14, 0 Right: 10, 18, 0	z = 2.65, p < .05
	High-Trust/Low-Distrust	Putamen	22, 14, -2	z = 2.43, p < .05
	High-Trust/Low-Distrust	Paracingulate cortex	6, 58, 2	z = 3.15, p < .01
Discredibility	High- Distrust /Low-Trust	Insular cortex	Left: -32, 22, -4 Right: 38, 18, -4	z = 3.79, p < .01
Malevolence	High- Distrust /Low-Trust	Amygdala	Left: -20, -4, -18 Right: 22, -2, -18	z = 4.05, p < .01
	High- Distrust /Low-Trust	Insular cortex	Left: -32, 22, -6 Right: 38, 20, -6	z = 1.80, p < .10 (non-significant at p < .05)

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