

*Supplemental materials for: High-level cognition is supported by information-rich but compressible brain activity patterns*

Lucy L. W. Owen<sup>1,2</sup> and Jeremy R. Manning<sup>1,\*</sup>

<sup>1</sup>Department of Psychological and Brain Sciences,  
Dartmouth College, Hanover, NH

<sup>2</sup>Carney Institute for Brain Sciences,  
Brown University, Providence, RI

\*Address correspondence to jeremy.r.manning@dartmouth.edu

March 11, 2024

Topic label	Cognitive label	Term 1	Term 2	Term 3	Term 4	Term 5	Term 6	Term 7	Term 8	Term 9	Term 10
Cognitive control and task performance	Cognitive control	tasks	control	network	conditions	comparison	common	experiment	correlates	pre	
Developmental aging and maturation	-	age	adults	children	development	performed	childhood	adult	adolescence	target	
Eye movements and visual attention	Attention	eye	gaze	eyes	visual	aging	gait	target	direction	facial	
Facial and voice recognition	Sensory perception	recognition	context	familiar	unfamiliar	movements	fluent	voices	agency	partner	
Social interaction and contextual behavior	Social cognition	semantic	game	human	interaction	familiarity	interactions	naming	target	phonological	
Language processing and semantic knowledge	Language processing	semantic	words	word	lexical	contextual	time	target	time	times	
Experimental design and behavioral performance	-	trials	stimulus	responses	trial	language	time	event	cont.	rs	
Genetic polymorphisms and risk factors	-	carriers	allele	gene	genotype	genetic	time	val	val	execution	
Sensorimotor integration and movement control	Motor control	motor	movement	movements	sensorimotor	finger	imagery	sensory	sensory	heroin	
Drug addiction and substance abuse	-	cocaine	users	drug	ppi	cannabis	craving	dependent	dependent	singing	
Music perception and auditory processing	Sensory perception	music	musical	pitch	auditory	sequences	listening	luteal	luteal	folicular	
Musical cycle and hormonal regulation	-	phase	women	cycle	phases	hf	sex	key	key	follicular	
Cognitive functions and role playing	Cognitive control	role	play	humans	plays	expression	critical	distinct	distinct	female	
Inhibition and gender differences	-	inhibition	women	inhibitory	sex	evidence	males	stop	male	female	
Somatosensory stimulation and motor control	Motor control	stimulation	stimulus	inhibitory	genotype	genetic	males	male	transcranial	sensory	
Sensory perception and cognition	Sensory perception	auditory	sound	inhibitory	ppi	finger	primary	transcranial	primary	modularities	
Social cognition	-	social	experience	inhibitory	musicians	cannabis	sound	primary	attachment	empathic	
Attention	-	target	targets	inhibitory	musicians	sequences	perspective	attachment	distractor	location	
Reward	-	design	blocks	inhibitory	auditory	hf	gesture	blocked	blocked	runs	
Alcohol cue reactivity	-	design	block	inhibitory	phases	expression	sex	key	key	preparatory	
Neuroimaging and metabolism	-	cue	cue	inhibition	plays	critical	metabolic	metabolic	metabolic	receptor	
Abnormalities in schizophrenia	Schizophrenia	pet	tonography	emission	genotype	critical	metabolic	metabolic	metabolic	schizophrenic	
Eating and body weight	-	food	controls	emission	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Sleep and olfactory processing	-	sleep	taste	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Alzheimer's disease and cognitive impairment	Sensory perception	ad	odor	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Working memory and executive function	-	memory	olfactory	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Moral decision making and phobias	Memory	adhd	disorder	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Language processing	-	individual	phobia	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Language laterality	Language processing	spatial	organization	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Attention	Attention	attention	asymmetry	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Resting-state brain activity in smokers	Resting state	reho	asymmetry	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Social cognition	Social cognition	social	attenuation	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Reward	Reward	reward	attenuation	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Attention	-	adhd	attenuation	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Spatial cognition	-	individual	attenuation	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Therapeutic interventions and deception	Sensory perception	training	acupuncture	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Neurodegenerative diseases and disorders	-	color	search	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Rewards and decision making	Cognitive control	disease	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
ADHD and attention deficits	-	conflict	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Neurobiological variability and individual diff...	-	volume	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Spatial cognition	-	fear	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Memory	-	learning	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Emotion	-	training	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Memory	-	frequency	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Neural oscillations and electrophysiology	Sensory perception	time	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Temporal dynamics of stimulus processing	-	time	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Tinnitus and hearing loss	Sensory perception	titmuss	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Abstract categories and representations	Language processing	category	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Pain perception and sensory stimulation	Sensory perception	pain	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Body and primates	-	body	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Phonological processing in reading	Language processing	reading	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Cognitive control	Cognitive control	rule	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Social cognition	-	asd	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Emotion	-	conflict	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Sensory perception	-	blind	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Blindsight and vision	Language processing	blind	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Deafness and sign language	-	risk	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Genetic risk and familial factors in psychosis	Motor control	action	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
PTSD and trauma	-	action	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Rule-based performance and complexity	Language processing	complexity	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Autism Spectrum Disorder (ASD) and social impair...	Cognitive control	autism	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Major depression disorder and emotions	-	ndd	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Pain perception and sensory stimulation	Sensory perception	ndd	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Body and primates	-	visual	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Phonological processing in reading	Language processing	genetic	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Action observation and imitation	Cognitive control	genetic	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Mental disorders and controls	-	genetic	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Personality and anxiety	Social cognition	anxiety	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Mental illness and math abilities	Cognitive control	mental	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Memory	Memory	priming	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Language processing	-	wm	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Resting state networks	Language processing	sentences	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Memory	Resting state	network	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Sensory perception	-	memory	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Blindsight and vision	Sensory perception	object	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Deafness and sign language	-	visual	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Genetic risk and familial factors in psychosis	Language processing	genetic	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Action observation and imitation	Cognitive control	genetic	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Cognitive performance and complexity	-	genetic	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Pharmacological effects of placebo and drug adm...	Cognitive control	genetic	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Personality and anxiety	-	genetic	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Mental illness and math abilities	Memory	genetic	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Priming and repetition effect	Memory	genetic	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Working memory and error monitoring	Sensory perception	genetic	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Sentence comprehension and syntax	-	genetic	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Episodic memory encoding and retrieval	Language processing	genetic	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Visual object recognition	-	genetic	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Effective causal modeling of neural networks	Language processing	genetic	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Relational reasoning and fluid intelligence	-	genetic	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Affective valence and fluid intelligence	Language processing	genetic	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Autobiographical memory in epilepsy	-	genetic	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	
Evidence and effect in behavioral studies	Memory	genetic	pd	reduced	genotype	critical	metabolic	metabolic	metabolic	metabolic	

Topic label	Cognitive label	Term 1	Term 2	Term 3	Term 4	Term 5	Term 6	Term 7	Term 8	Term 9	Term 10
Stress and physiological responses	-	cortisol	autonomic	heart	responses	rate	regulation	physiological	induced		
Speech and language processing	Language processing	tds	language	perception	comprehension	acoustic	acoustic	linguistic	prosody		
Network interactions and evidence in human systems	-	evidence	systems	support	process	integration	integration	provide	engaged		
Neuroimaging techniques	-	images	time	void	test	distinct	test	clinical	mapping		
Visual perception of motion and form	Sensory perception	visual	perceptual	image	spatial	spatial	human	static	illusion		
Emotional processing and regulation	Emotion	emotion	facial	biological	dynamic	moving	negative	regulation	emotions		
				expressions	affective	responses					

**Table S1: Neurosynth-derived topics.** We report the top-weighted terms for each of 80 topics identified using Latent Dirichlet Allocation (Blei et al., 2003) applied to 9,204 functional neuroimaging articles in the Neurosynth database (Rubin et al., 2017). See *Reverse inference* for additional information.

Cognitive label	Rank
Cognitive control	10
Language processing	9
Memory	8
Emotion	7
Social cognition	6
Spatial cognition	5
Attention	4
Reward	3
Sensory perception	2
Motor control	1
Resting state	0

Table S2: **Ranking cognitive processes.** The table displays the output of a ChatGPT (OpenAI, 2023) prompt asking for a ranking of the cognitive processes reflected in the labels from Table S1. See *Ranking cognitive processes* for additional detail.

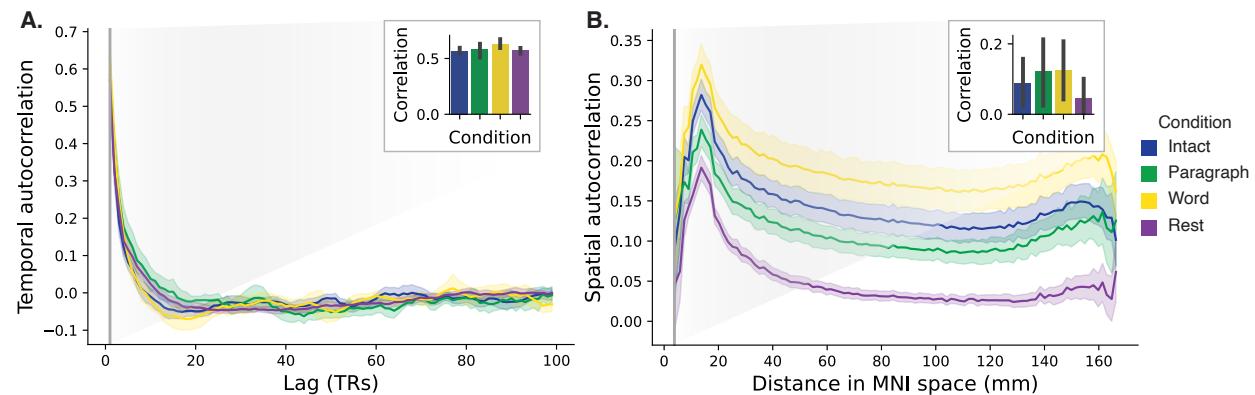


Figure S1: **Autocorrelations.** **A. Temporal autocorrelations.** The panel displays the average correlation (taken across all nodes and participants) for each experimental condition (color), as a function of offset lag (in TRs). **B. Spatial autocorrelations.** The panel displays the average correlation between the activation timeseries for each pair of nodes, for each experimental condition (color), as a function of distance (in mm). Error ribbons in both panels denote bootstrap-estimated across-participant 95% confidence intervals.

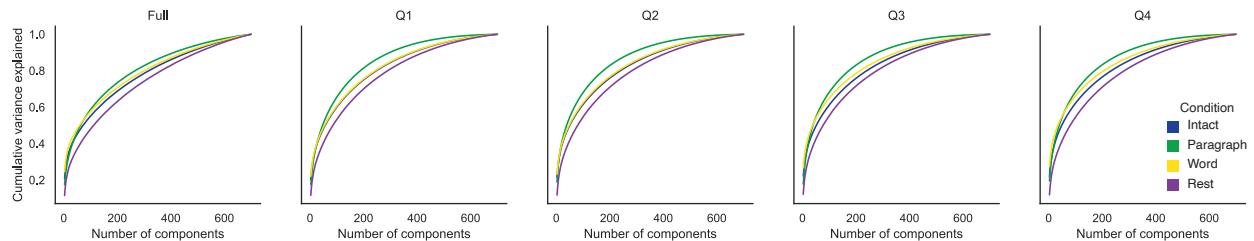
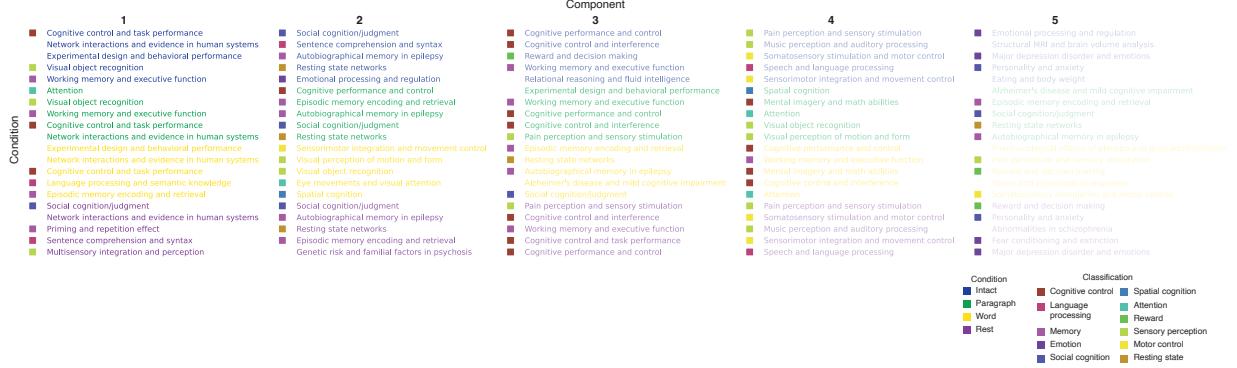
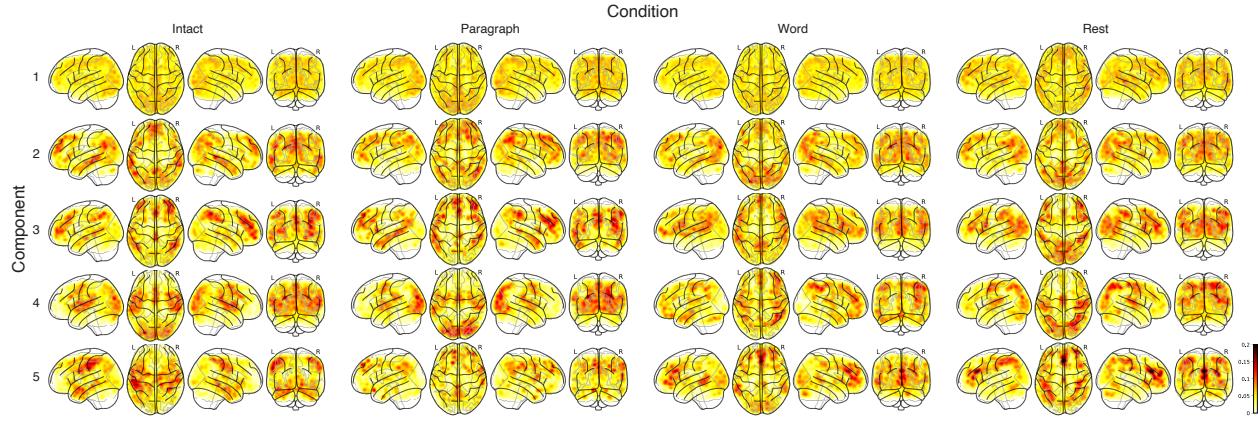


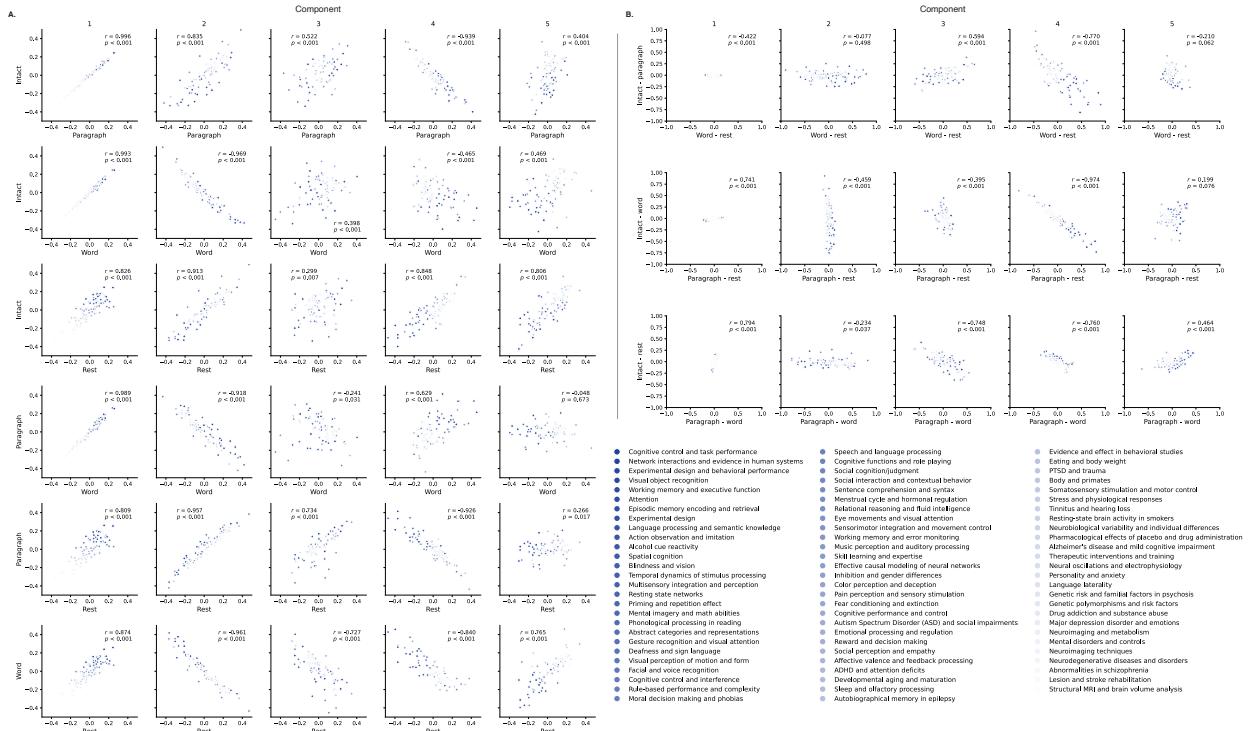
Figure S2: **Cumulative variance explained by component, condition, and part.** Each panel displays the cumulative variance explained in the neuroimaging data as a function of the number of principal components. Colors denote experimental conditions. The left panel displays results for all data, and the right panels display results separated by story segment (Q1: first quarter; Q2: second quarter; Q3: third quarter; Q4: fourth quarter).



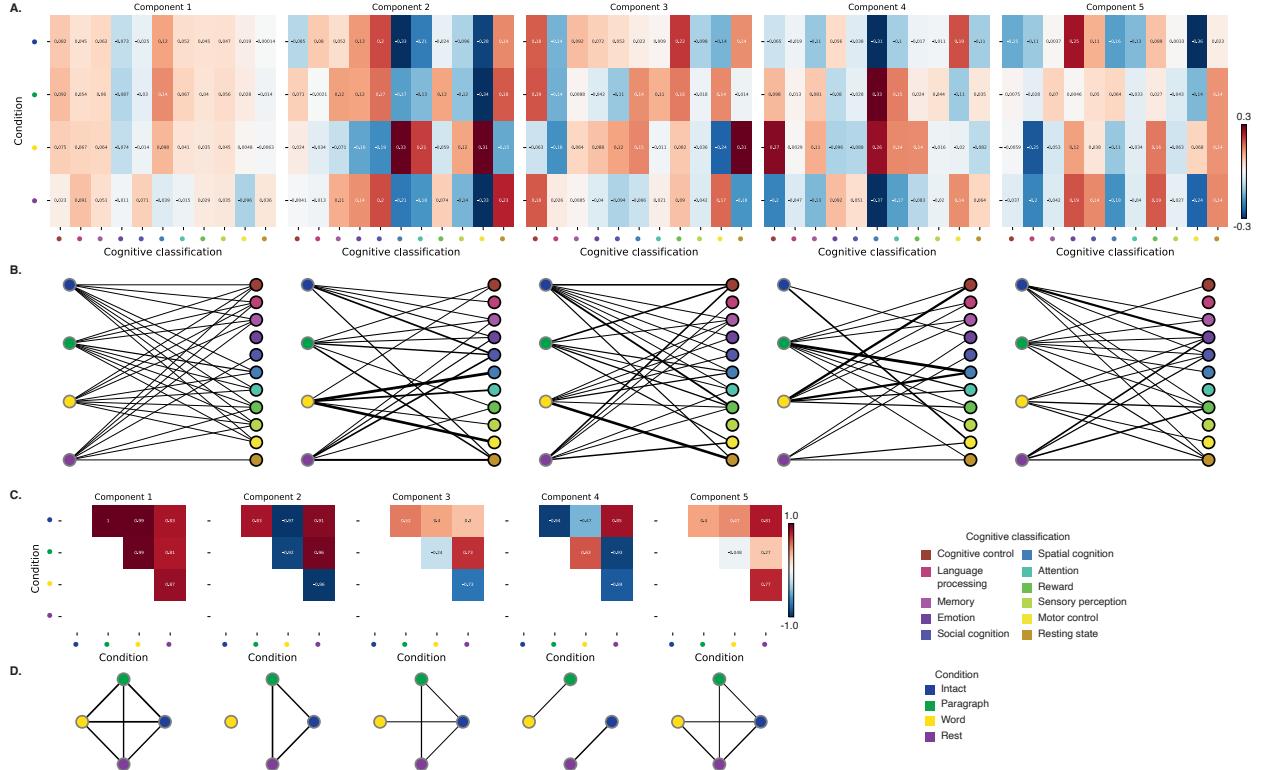
**Figure S3: Highest-weighted topics associated with the highest-weighted components by condition, broken down by story segment.** Each group of five rows corresponds to an experimental condition (denoted by color, as indicated in the legend in the lower right), and the columns and shading correspond to the component number (ranked by proportion of variance explained). The colored squares in front of many of the topics denote manually identified cognitive labels (Tab. S1).



**Figure S4: Brain maps by component and condition.** For the top five highest-weighted principal components (rows), from each experimental condition (columns), the components' brain maps are projected onto four views: left sagittal, axial, right sagittal, and coronal. The color scale is the same for all panels and matches the coloring in Figure 5C.



**Figure S5: Comparisons between per-component topic correlations across conditions.** Each sub-panel displays a scatterplot comparing the per-topic correlations for two or more experimental conditions. Each dot denotes the correlations for a single topic (indicated by the legend on the right). The topics are colored according to the ranked order of the correlations between the topic's brain maps and the brain map for the first principal component in the intact condition. **A. Comparisons between correlations for each pair of experimental conditions.** The conditions being compared are marked on the x and y axes. Each sub-panel (column) reflects the correlations for one principal component. **B. Comparisons between differences in correlations for pairs of experimental conditions.** In these sub-panels, the x and y coordinates reflect differences in correlations for the indicated experimental conditions, for the given component (column). All panels: the across-topic correlations reported in each panel are between each topic's x and y coordinates.



**Figure S6: Functions associated with top-weighted components by condition.** **A. Top-weighted topics by condition.** Here we display per-condition (rows, indicated by colored dots) topic correlations, averaged across topics that pertain to each of several broad cognitive functions (columns within each sub-panel, indicated by colored dots). Each sub-panel reflects correlations for the components indicated in the panel titles. A legend for the condition and cognitive function classifications is displayed in the lower right of the figure. Table S1 provides a list of each topic's top-weighted terms, along with each topic's manually labeled cognitive classification. A full list of the topics most highly associated with each component may be found in Figure S3. **B. Associations between per-condition components and cognitive functions.** The network plots denote positive average correlations between the component images for each condition (gray-outlined dots on the left sides of each network; colors denote conditions) and topic-specific brain maps associated with each indicated cognitive function (black-outlined dots on the right sides of each network; colors denote cognitive functions). The line thicknesses are proportional to the correlation values (correlation coefficients are noted in the heat maps in Panel A). **C. Correlations between each principal component, by condition.** The heat maps display the correlations between the brain maps (Fig. S4) for each principal component (sub-panel), across each pair of conditions (rows and columns of each sub-panel's matrix, indicated by colored dots). **D. Associations between per-condition topic weights, by component.** Each sub-panel's network plot summarizes the pattern of correlations between the topic correlations from each of the  $n^{\text{th}}$  top-weighted principal components (sub-panel), for each experimental condition (gray-outlined dots). The line thicknesses are proportional to the correlation values (correlation coefficients are noted in the heat maps in Panel C).

## Supplemental references

1. Blei, D. M., Ng, A. Y., & Jordan, M. I. (2003). Latent dirichlet allocation. *Journal of Machine Learning Research*, 3, 993–1022.
2. OpenAI. (2023). *ChatGPT*. <https://chat.openai.com>.
3. Rubin, T. N., Kyoejo, O., Gorgolewski, K. J., Jones, M. N., Poldrack, R. A., & Yarkoni, T. (2017). Decoding brain activity using a large-scale probabilistic functional-anatomical atlas of human cognition. *PLoS Computational Biology*, 13(10), e1005649.