How do different modalities of thought (verbal, visual, abstract) show distinct neural signatures and processing mechanisms?

Brain imaging reveals that verbal, visual, and abstract thinking each engage separate neural systems, with distinct activation patterns in language, perceptual, and frontotemporal regions respectively, while sharing some overlap in integration areas.

Abstract

Verbal, visual, and abstract thought each engage distinct neural systems. Studies using fMRI and meta-analyses report that verbal thought reliably recruits left-lateralized language regions—especially the inferior frontal and supramarginal gyri—supporting functions such as semantic retrieval and phonological processing. In contrast, visual thought engages occipital and fusiform regions along with parietal areas that underpin perceptual coding and mental imagery.

Abstract processing shows a signature pattern that centers on the left inferior frontal gyrus and a frontotemporal subdivision of the default mode network, a configuration that diverges from the patterns observed for concrete or visually based processing. Several reports indicate that higher-order association regions (including parts of the default mode network and parahippocampal/retrosplenial cortices) mediate cross-modal integration, while tasks involving working memory demonstrate dynamic adjustments that favor one modality over another.

Together, the studies support the conclusion that each modality of thought—verbal, visual, and abstract—is underpinned by distinct neural activations and processing mechanisms, with limited but functionally significant overlap in integration regions.

Paper search

Using your research question ”How do different modalities of thought (verbal, visual, abstract) show distinct neural signatures and processing mechanisms?”, we searched across over 126 million academic papers from the Semantic Scholar corpus. We retrieved the 50 papers most relevant to the query.

Screening

We screened in sources that met these criteria:

- **Thought Modalities**: Does the study examine at least one of the following modalities of thought: verbal processing, visual imagery, or abstract conceptual processing?
- **Neuroimaging Methods**: Does the study use at least one neuroimaging technique (fMRI, EEG, MEG, or PET)?
- **Experimental Design**: Does the study employ a task-based experimental design that compares different thought modalities?
- **Participant Population**: Does the study include healthy adult participants aged 18-65?
- **Sample Size**: Does the study include at least 15 participants?
- **Measurement Types**: Does the study include both behavioral and neural measurements?
- **Population Type**: Does the study include healthy participants without focusing exclusively on clinical populations?
- **Modality Comparison**: Does the study compare multiple modalities rather than examining only one modality in isolation?

We considered all screening questions together and made a holistic judgement about whether to screen in each paper.

Data extraction

We asked a large language model to extract each data column below from each paper. We gave the model the extraction instructions shown below for each column.

- **Study Design Type**:

  Identify the primary research design used in the study. Look in the methods section for explicit description of the study type. Categorize as:

- Functional Magnetic Resonance Imaging (fMRI) study
- Positron Emission Tomography (PET) study
- Event-related neuroimaging study
- Neuroimaging meta-analysis
- Other (specify)

If multiple design elements are present, list all relevant types. If unclear, note ”design not clearly specified”.

- **Neuroimaging Modalities and Techniques**:

  Extract specific neuroimaging techniques used in the study. Look in methods section for:

- Specific neuroimaging technology (fMRI, PET)
- Scanning parameters
- Data analysis techniques (e.g., multilevel kernel density analysis, event-related design)

Record precise details, including:

- Scanning equipment specifications
- Scanning parameters (e.g., TR, TE)
- Data processing methods

- **Participant Demographics**:

  Extract comprehensive participant information:

- Total number of participants
- Age range or mean age
- Gender distribution
- Neurological status (healthy adults, specific conditions)

If multiple groups are present, extract details for each group separately. If any demographic information is missing, note ”not reported”.

Preferred format:

- Total n = [number]
- Mean age: [value] years
- Gender: [% male/female]
- Neurological status: [description]

- **Concept Types and Stimuli**:

  Identify and categorize the types of conceptual stimuli used:

- Concrete vs. abstract word categories
- Presentation format (single words, sentences)
- Specific examples of stimuli used
- Criteria for categorizing concepts

Record:

- Total number of stimuli
- Specific classification method
- Any normalization or standardization of stimuli

If multiple stimulus types are used, provide details for each type.

- **Experimental Conditions and Contrasts**:

  Extract details about experimental conditions:

- Primary contrast conditions (e.g., abstract > concrete, concrete > abstract)
- Control conditions
- Specific cognitive tasks performed during imaging

Record:

- Exact description of each condition
- Rationale for condition selection
- Any specific instructions given to participants

If multiple contrasts are analyzed, list all relevant comparisons.

- **Key Neural Activation Regions**:

  Identify and extract neural activation patterns:

- Specific brain regions activated
- Lateralization of activation (left/right hemisphere)
- Intensity or extent of activation
- Statistical significance of findings

Preferred format:

- Region: [specific anatomical location]
- Activation pattern: [description]
- Statistical significance: [p-value, effect size]

Include both concrete and abstract concept processing regions.

Results

Characteristics of Included Studies

Study	Methodology	Brain Regions Studied	Modalities Examined	Key Findings
Straube et al., 2013	Event-related functional magnetic resonance imaging (fMRI)	Inferior frontal gyrus (IFG), temporal pole, medial frontal, occipital, parietal, angular gyrus	Speech (sentences), gestures (emblematic/tool-use), abstract-social vs. concrete-object	Left-hemispheric network for abstract information; modality-specific activations for gestures (bilateral occipital/parietal/temporal, right IFG) and speech (left anterior temporal, angular gyrus)
Kraemer et al., 2009	Event-related fMRI	Fusiform gyrus, supramarginal gyrus	Visual (pictures), verbal (words), cognitive style	Fusiform gyrus (visualizer), supramarginal gyrus (verbalizer); modality-specific cortical activity
Simmons et al., 2003	fMRI	Modality-specific sensory/motor systems	Verbal (linguistic), six modalities (vision, audition, motor, touch, taste, smell)	Significant activation in respective neural systems for each modality during conceptual processing
Binder et al., 2005	Event-related fMRI	Left lateral temporal, angular gyrus, dorsal prefrontal, left IFG	Verbal (single words), concrete vs. abstract	Overlapping but distinct systems: concrete (bilateral angular gyrus, dorsal prefrontal), abstract (left IFG)
Crottaz-Herbette et al., 2004	fMRI	Dorsolateral prefrontal cortex (DLPFC), ventrolateral prefrontal cortex (VLPFC), intraparietal sulcus (IPS), supramarginal gyrus, basal ganglia	Auditory and visual verbal working memory	Shared and modality-specific prefrontal/parietal responses; left DLPFC (auditory), left IPS (visual)

Study	Methodology	Brain Regions Studied	Modalities Examined	Key Findings
Amit et al., 2017	Behavioral + fMRI	Left frontal (orbital IFG, IFG, middle frontal gyrus), temporal/parietal (anterior temporal, posterior temporal, angular gyrus), fusiform face area (FFA), extrastriate body area (EBA)	Verbal (inner speech), visual (imagery), recall vs. perception	Visual imagery engaged in both verbal and visual thought; inner speech more specific to verbal thought
Wang et al., 2010	Neuroimaging meta-analysis (fMRI, positron emission tomography (PET))	IFG, middle temporal gyrus (MTG), precuneus, parahippocampal, posterior cingulate, fusiform	Verbal (words, sentences), abstract vs. concrete	Abstract: IFG, MTG; Concrete: precuneus, parahippocampal, posterior cingulate, fusiform
Hoffman and Bair, 2025	Neuroimaging meta-analysis	Visual/action regions, default mode network (DMN; medial temporal, frontotemporal)	Concrete (sentences), abstract (single words), social/language	Concrete: visual/action, medial temporal DMN; Abstract: social/language, frontotemporal DMN
Sabsevitz et al., 2005	Event-related fMRI	Ventral temporal, posterior parietal, dorsal prefrontal, posterior cingulate, superior temporal, inferior frontal	Verbal (word triads), concrete vs. abstract	Concrete: bilateral ventral temporal/parietal/prefrontal/cingulate; Abstract: left superior temporal/inferior frontal
Konkle et al., 2015	fMRI	Parahippocampal, transverse occipital sulcus, retrosplenial, lateral occipital, fusiform	Visual (pictures), auditory (words), semantic categories	Shared regions for pictures/words (inanimate); pictorial-specific regions (animate)

Methodology:

- Event-related fMRI:4 studies
- fMRI (not specified as event-related):3 studies
- Behavioral + fMRI:1 study
- Neuroimaging meta-analysis (fMRI, PET):1 study
- Neuroimaging meta-analysis (unspecified imaging):1 study

Modalities Examined (studies may be counted in multiple categories):

- Verbal/language-based modalities:10 studies
- Visual modalities:5 studies
- Auditory modalities:3 studies
- Gesture, motor, touch, taste, and smell:1 study each
- Abstract vs. concrete concepts:5 studies
- Explicit comparison of multiple modalities within the same experiment:6 studies

Key Findings:

- Modality-specific activations:9 studies
- Shared or overlapping activations across modalities:3 studies
- Distinctions between abstract and concrete processing:5 studies, with different brain regions implicated for each
- Overlapping but distinct systems for abstract and concrete concepts:1 study
- Distinction between social/language and visual/action networks for abstract and concrete content:1 study

Among the included studies, we did not find any that examined only a single sensory modality without also referencing verbal/visual or abstract/concrete distinctions. Most studies included multiple modalities or compared abstract and concrete processing.

Thematic Analysis

Neural Signatures Across Modalities

Brain Region	Verbal Processing	Visual Processing	Abstract Processing
Left inferior frontal gyrus (IFG)	Engaged in verbal/abstract tasks (Binder et al., 2005; Wang et al., 2010; Sabsevitz et al., 2005)	Not primary	Key for abstract concepts (Straube et al., 2013; Wang et al., 2010)
Fusiform gyrus	Not primary	Visualizer region (Kraemer et al., 2009); concrete concepts (Wang et al., 2010; Sabsevitz et al., 2005)	Not primary
Supramarginal gyrus	Verbalizer region (Kraemer et al., 2009)	Engaged in visual tasks for verbalizers (summary, not directly cited)	Not primary
Angular gyrus	Bilateral for concrete (Binder et al., 2005)	Not primary	Not primary

Brain Region	Verbal Processing	Visual Processing	Abstract Processing
Dorsolateral prefrontal cortex (DLPFC)	Bilateral, more for concrete (Sabsevitz et al., 2005); left DLPFC for auditory visual working memory (Crottaz-Herbette et al., 2004)	Not primary	Not primary
Precuneus/Parahippocampal	Not primary	Concrete concepts (Wang et al., 2010; Hoffman and Bair, 2025)	Not primary
Medial temporal default mode network (DMN)	Not primary	Concrete concepts (Hoffman and Bair, 2025)	Not primary
Frontotemporal DMN	Not primary	Not primary	Abstract concepts (Hoffman and Bair, 2025)
Fusiform face area (FFA)/extrastriate body area (EBA)	Not primary	Visual imagery (Amit et al., 2017)	Not primary

Verbal Processing:

- Primary regions implicated:
  - Left inferior frontal gyrus (3 studies: Binder et al., 2005; Wang et al., 2010; Sabsevitz et al., 2005)
  - Supramarginal gyrus (1 study: Kraemer et al., 2009)
  - Angular gyrus (1 study: Binder et al., 2005; for concrete concepts)
  - Dorsolateral prefrontal cortex (2 studies: Sabsevitz et al., 2005; Crottaz-Herbette et al., 2004; for concrete/auditory visual working memory)
- No studies in our set implicated the other regions as primary for verbal processing.

Visual Processing:

- Primary regions implicated:
  - Fusiform gyrus (3 studies: Kraemer et al., 2009; Wang et al., 2010; Sabsevitz et al., 2005)
  - Supramarginal gyrus (engaged in visual tasks for verbalizers, based on summary)
  - Precuneus/parahippocampal (2 studies: Wang et al., 2010; Hoffman and Bair, 2025)
  - Medial temporal DMN (1 study: Hoffman and Bair, 2025)
  - Fusiform face area/extrastriate body area (1 study: Amit et al., 2017)
- No studies in our set implicated the other regions as primary for visual processing.

Abstract Processing:

- Primary regions implicated:
  - Left inferior frontal gyrus (2 studies: Straube et al., 2013; Wang et al., 2010)
  - Frontotemporal DMN (1 study: Hoffman and Bair, 2025)
- No studies in our set implicated the other regions as primary for abstract processing.

Concrete vs. Abstract:

- Regions specifically implicated for concrete concepts:Angular gyrus, dorsolateral prefrontal cortex, fusiform gyrus, precuneus/parahippocampal, and medial temporal DMN.
- Regions specifically implicated for abstract concepts:Left inferior frontal gyrus and frontotemporal DMN.

Modality-Specific Processing Mechanisms

- Verbal processing (including abstract concepts):Supported by left-lateralized language networks, particularly the inferior frontal gyrus and temporal cortex.
- Visual processing (including imagery and concrete concepts):Associated with activation in the fusiform gyrus, occipital cortex, and parietal regions.
- Modality-specific mechanisms:Evident in working memory (Crottaz-Herbette et al., 2004), cognitive style (Kraemer et al., 2009), and property verification (Simmons et al., 2003).
- Supramodal or cross-modal processing:Most evident in higher-order association areas and default mode network components (Straube et al., 2013; Hoffman and Bair, 2025).
- Asymmetry in engagement:Some studies (Amit et al., 2017) suggest visual imagery is more universally engaged than inner speech, even during verbal thought.

Cross-Modal Integration and Interaction

- Integration regions:Several studies (Straube et al., 2013; Konkle et al., 2015) report regions such as the parahippocampal and retrosplenial cortex integrating information across modalities.
- Cross-modal inhibitory processes:Suggested in working memory (Crottaz-Herbette et al., 2004), where activation in one modality suppresses the other.
- Default mode network (DMN):Plays a key role in integrating social, spatial, and semantic information across modalities (Hoffman and Bair, 2025).
- Integration vs. segregation:The degree of integration versus segregation of modality-specific processing varies by task and stimulus type.

Temporal and Spatial Dynamics

- Temporal dynamics:Event-related designs (Straube et al., 2013; Binder et al., 2005; Sabsevitz et al., 2005) allow examination of temporal dynamics, though most studies focus on spatial localization.
- Spatial distinctions:Clear distinction between perceptual (posterior, bilateral) and language/abstract (anterior, left-lateralized) regions.
- Dynamic suppression:Some studies (Crottaz-Herbette et al., 2004) report dynamic suppression of non-task-relevant sensory cortices, suggesting temporal gating of information flow.
- Spatial organization of object categories:(Konkle et al., 2015) shows both convergence and divergence across modalities, with some regions responding similarly to pictures and words, and others being modality-specific.

Synthesis of Findings

Processing Type	Neural Signature	Mechanism	Cross-Modal Effects
Verbal/Abstract	Left inferior frontal gyrus, middle temporal gyrus, language network, frontotemporal default mode network	Semantic retrieval, phonological processing, working memory	Supramodal integration in higher-order association areas; visual imagery may be engaged (Amit et al., 2017)
Visual/Concrete	Fusiform, occipital, parietal, medial temporal default mode network	Perceptual processing, mental imagery, object recognition	Bilateral activation; cross-modal suppression in working memory; shared regions for pictures/words (Konkle et al., 2015)
Cross-Modal	Parahippocampal, retrosplenial, default mode network	Integration of sensory, motor, and semantic information	Default mode network specialization for social/spatial/semantic models; cross-modal inhibitory and integrative processes

Summary of Patterns Across Processing Types:

- Neural signatures:
  - Each processing type is associated with a distinct set of brain regions.
  - The default mode network is referenced in all three processing types, but with different subregions (frontotemporal, medial temporal, general).
- Mechanisms:
  - Each processing type is linked to a unique set of cognitive operations.
  - No mechanism was mentioned in more than one processing type.
- Cross-modal effects:
  - Each processing type is associated with different cross-modal effects.
  - No cross-modal effect was mentioned in more than one processing type.
- Study representation:
  - We did not find any processing type represented in more than one study.
  - Default mode network involvement was the only neural signature shared across all processing types, though with different subregions. All other neural signatures, mechanisms, and cross-modal effects were unique to their respective processing type.

Limitations

- Several studies lack full demographic or statistical reporting, limiting assessment of internal validity.
- Heterogeneity in tasks, stimuli, and analytic approaches complicates direct comparison and synthesis.
- Meta-analyses provide higher-level integration but may be affected by variability in included studies.
- The evidence base is strongest for healthy adults; generalizability to other populations is uncertain.

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