Mapping The Complete Hierarchical Brain Pathways Involved In Processing Basic Elements Of Naturalistic Stimuli

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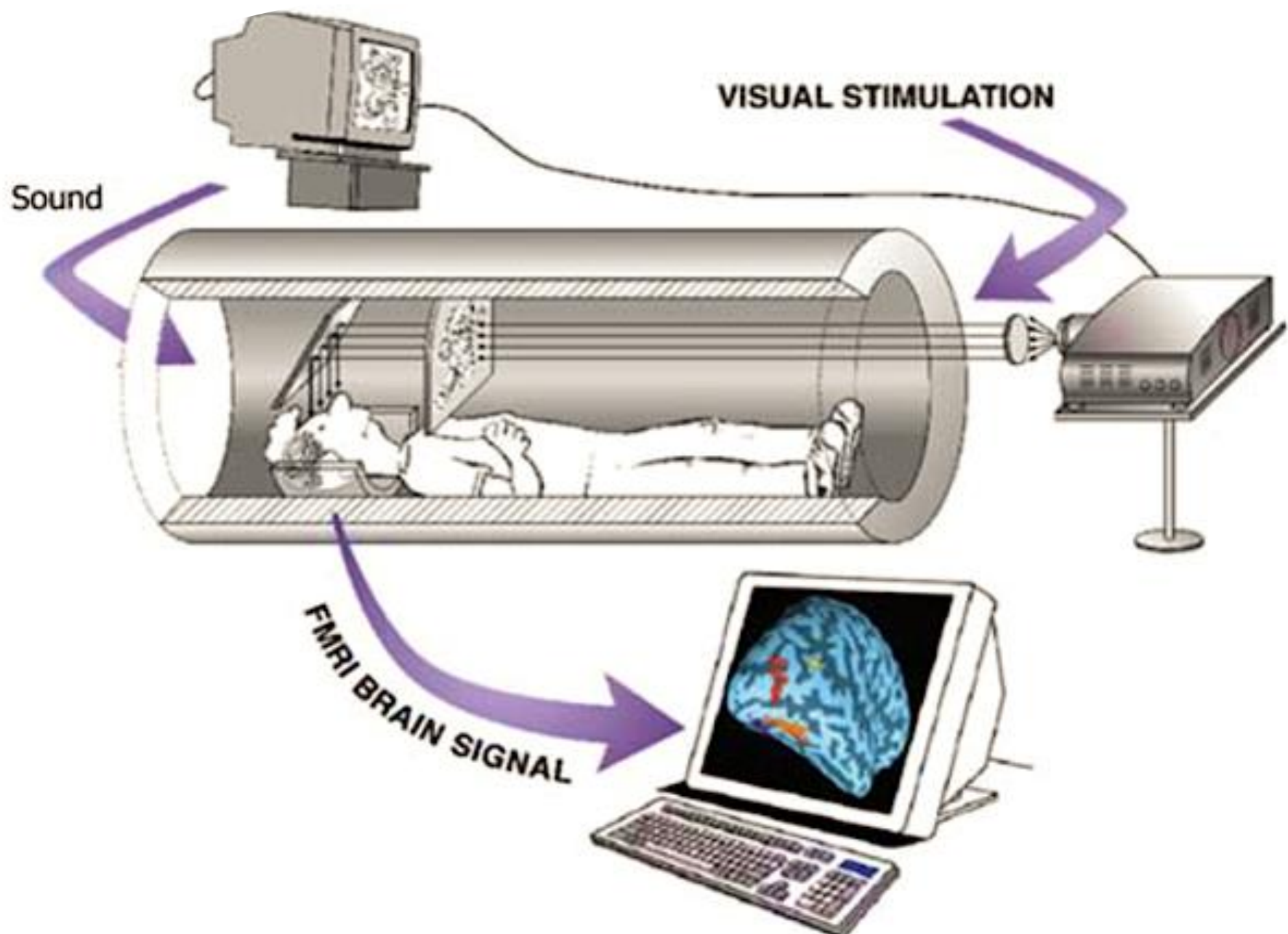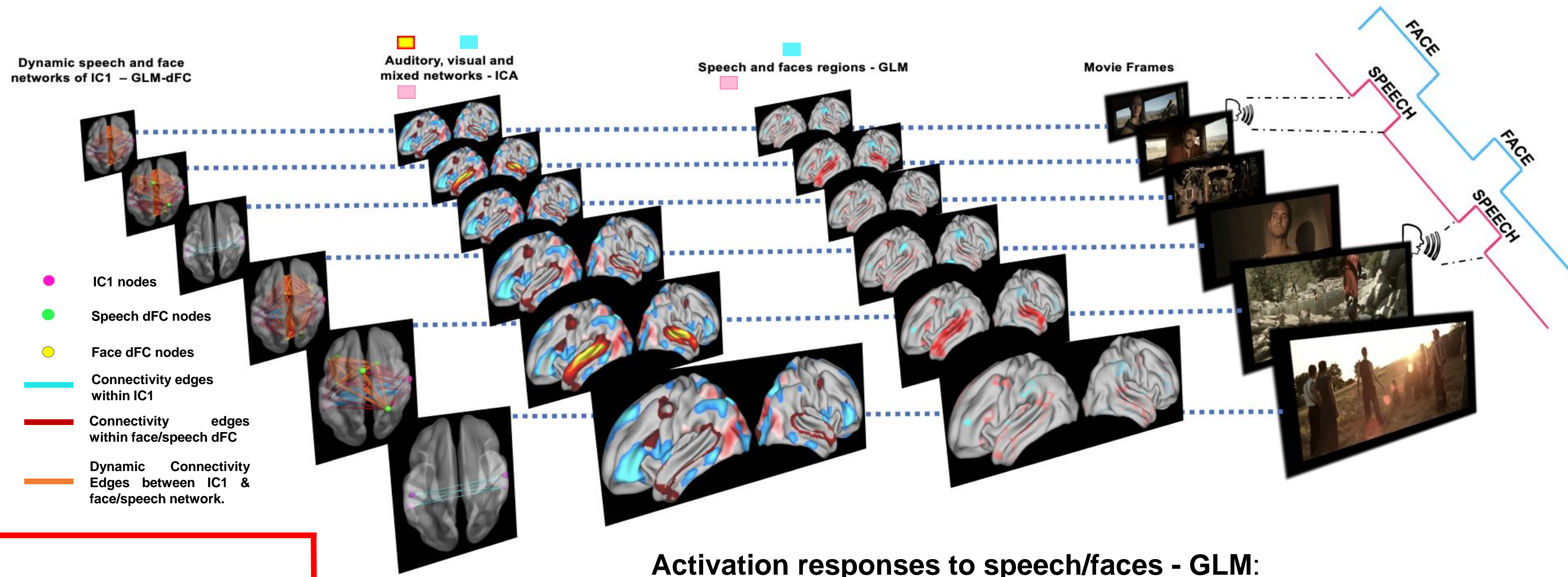
1 The Brain In Nature And Movies

Figure: Example of movie-watching fMRI experimental paradigm. There were 34 participants in our study.

- **Natural environment and everyday life** - enriched with complex combinations of dynamically changing stimuli, and diverse actions and interactions.
- Two main hierarchical levels of brain regions involved in processing this:
  - **Low-level regions** → for simpler functions like sensory perception;
  - **High-level regions** → for complex functions like cognitive & emotional processing.
- **Our objective** – To map the hierarchical processing of simple elements of naturalistic stimuli in the brain → To hence understand how changing these elements can influence the hierarchical activity, and in turn, high-level responses of individuals.
- **Modality used** – functional Magnetic Resonance Imaging (fMRI) → to map functional activity of brain non-invasively by detecting corresponding changes in blood oxygen level (BOLD).
- **Experimental paradigm** – Movie watching, non-constrained and naturalistic (as shown in figure).

2 Mapping Brain Activity Responding to Faces and Speech In The Movie

Hypothesis-driven General Linear Model (GLM) – To identify which brain regions change their activation levels in response to occurrence of speech/faces in the movie.
- Recovers low-level regions, responding commonly, in all viewers.

Data-driven tensor Independent Component Analysis (ICA) - To identify brain regions that maintain synchronization throughout the movie → functional networks
- Recovers low-level & hierarchical functional networks common in all viewers, through IC maps.
- Functional networks not specifically related to speech/faces – result of correlation analysis

Dynamic functional connectivity (dFC) analysis - To identify time-varying functional networks formed with seed region that is obtained from GLM or ICA.
- Recovers low-level & hierarchical dynamic functional networks in each viewer.
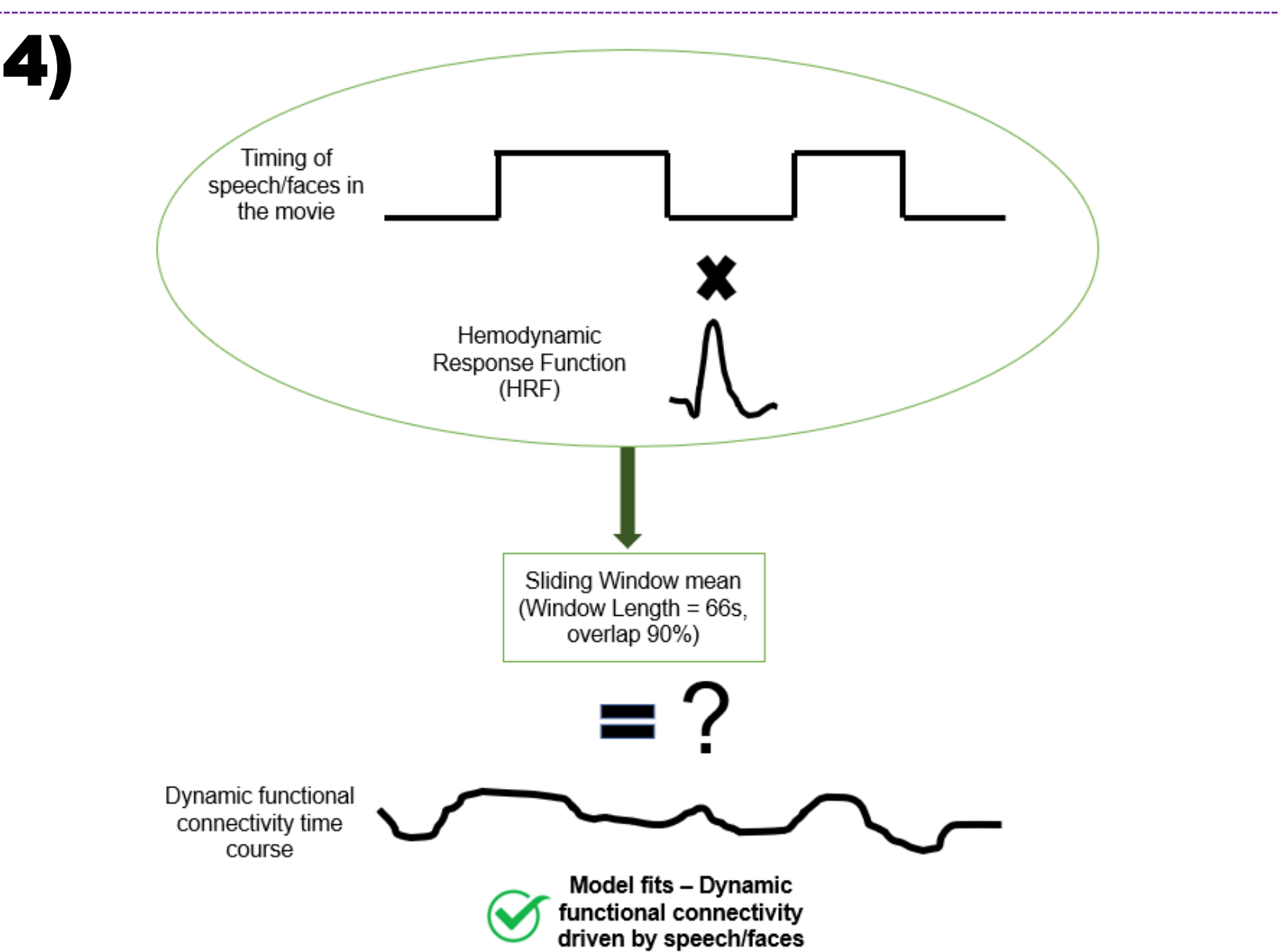
GLM-dFC – To identify those dynamic functional networks that are formed by seed region when specifically driven by speech/faces.
- Recovers low-level & hierarchical dynamic functional networks driven by speech/faces, commonly in all viewers.
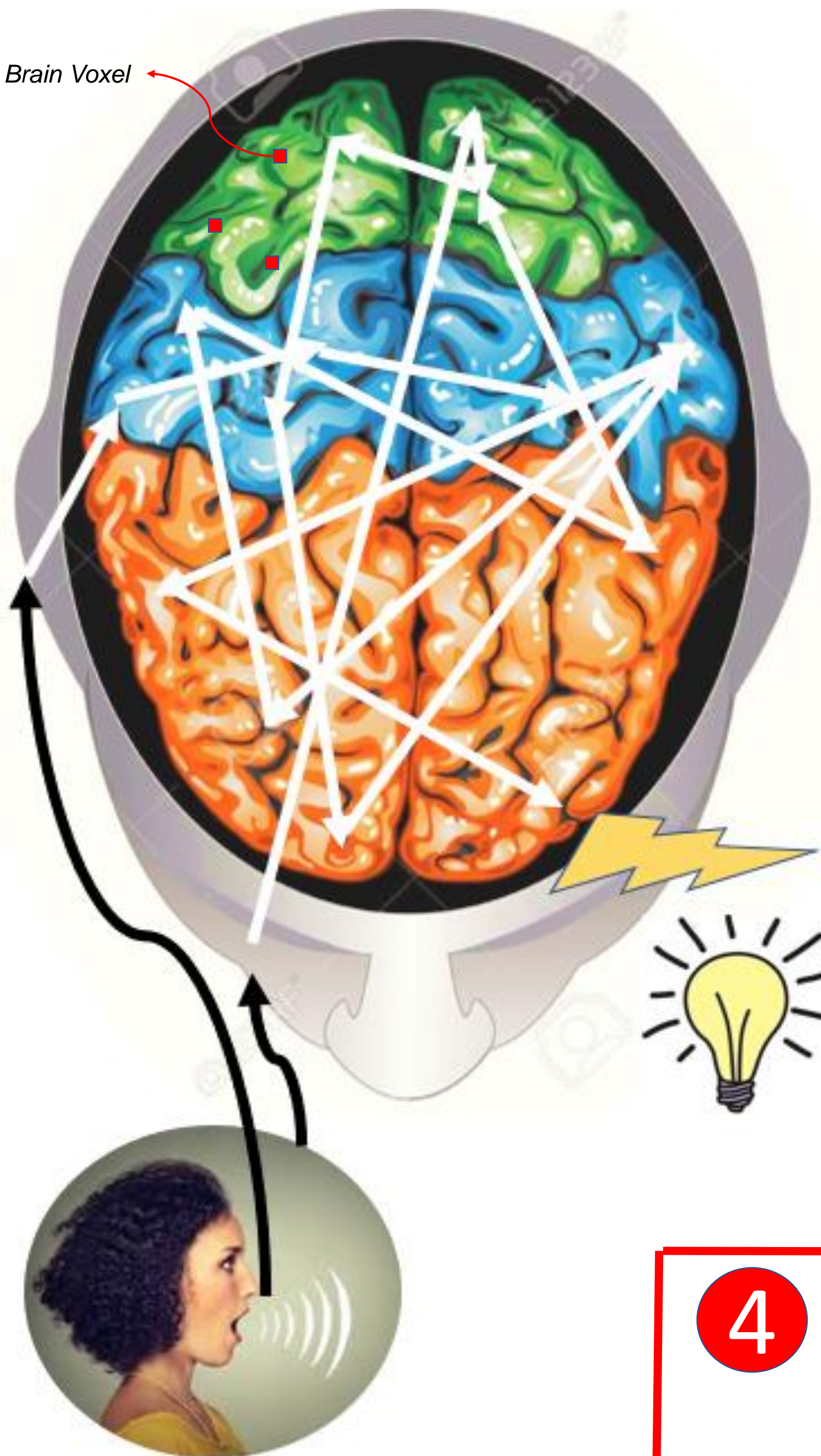
Hence, **complete unique hierarchical pathways** from low-level sensory to high-level cognitive brain regions, involved in processing the basic elements of complex naturalistic stimuli:
- Have **static** (recovered from GLM & ICA) as well as **dynamic** (recovered from GLM-dFC) networks; and
- Can be **mapped using GLM-dFC**, with seeds from GLM and ICA.

3 The Nature of Brain Activity Involved In Processing Faces And Speech In The Movie

- IC1 nodes
- Speech dFC nodes
- Face dFC nodes
- Connectivity edges within IC1
- Connectivity edges within face/speech dFC
- Dynamic Connectivity Edges between IC1 & face/speech network.

Activation responses to speech/faces - GLM:

Feature	Level Of Processing	Brain Areas
Speech	Low-Level Speech & Language	Parts of Temporal Lobe
Faces	Low-Level Visual & Faces	Parts of Occipital & Temporal Lobes

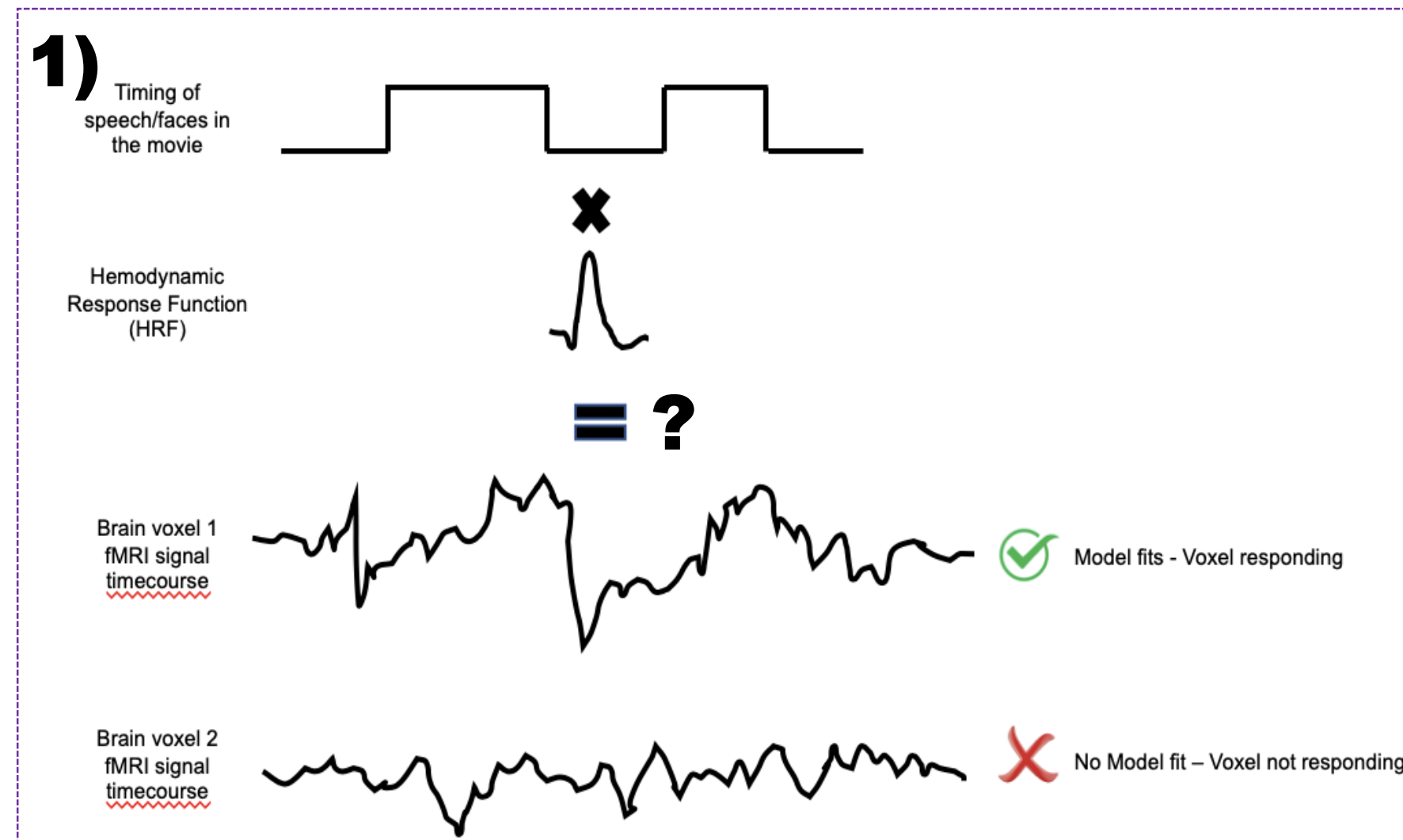**Top 7 Low-level and hierarchical functional networks during movie - ICA:**

IC	Level Of Processing	Brain Areas
IC1, IC2, IC3	Low-Level Speech & Language	Parts of Temporal Lobe
IC4, IC6	Low-Level Visual & Face, and High-Level Cognitive	Parts of Occipital, Temporal, Parietal and Frontal Lobes
IC5, IC7	Low-Level Visual & Auditory, and High-Level Cognitive & Emotional	Parts of Occipital, Temporal, Frontal Lobes and Precuneus

Hierarchical functional networks responding to speech/faces - GLM-dFC:.

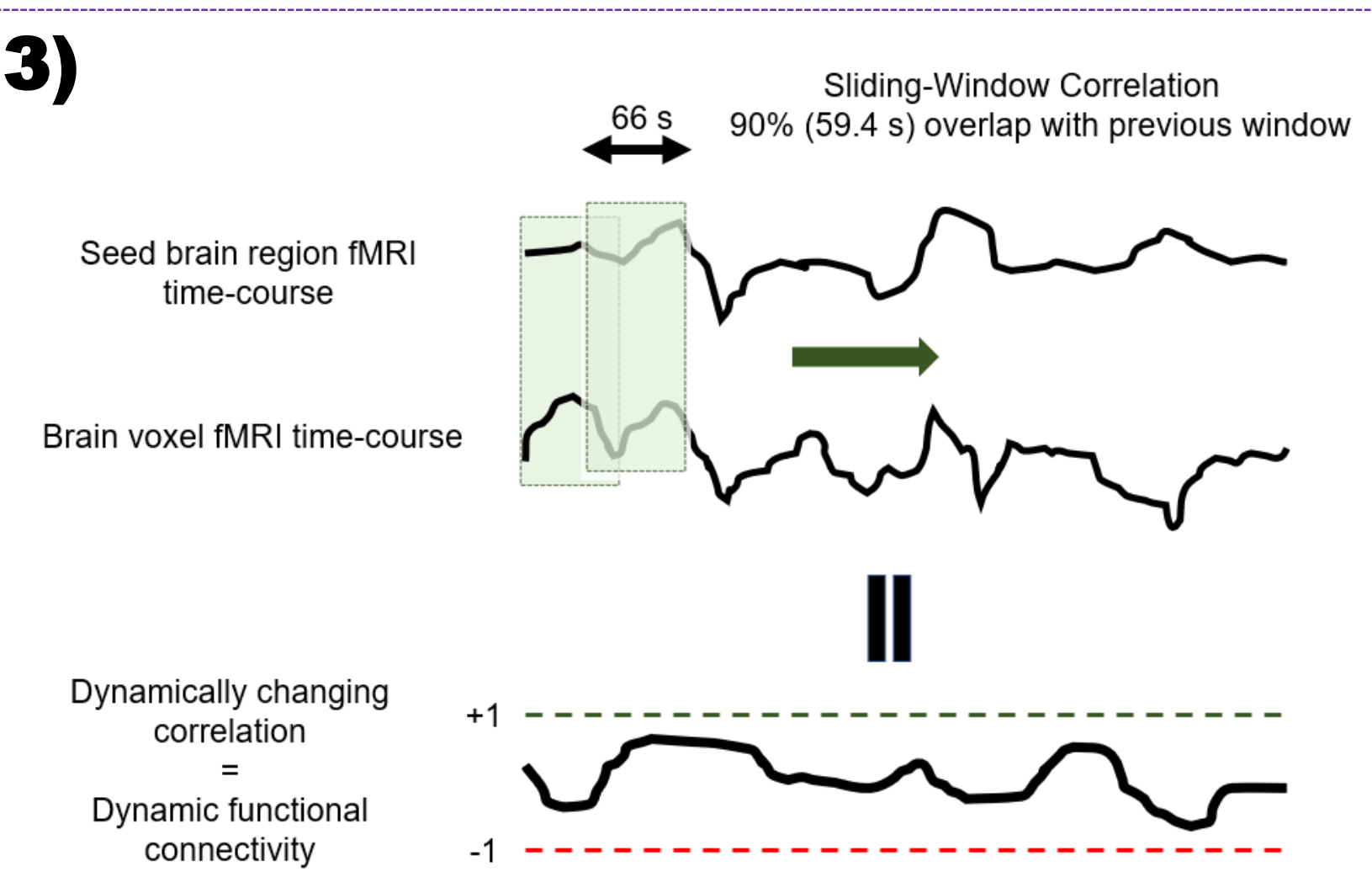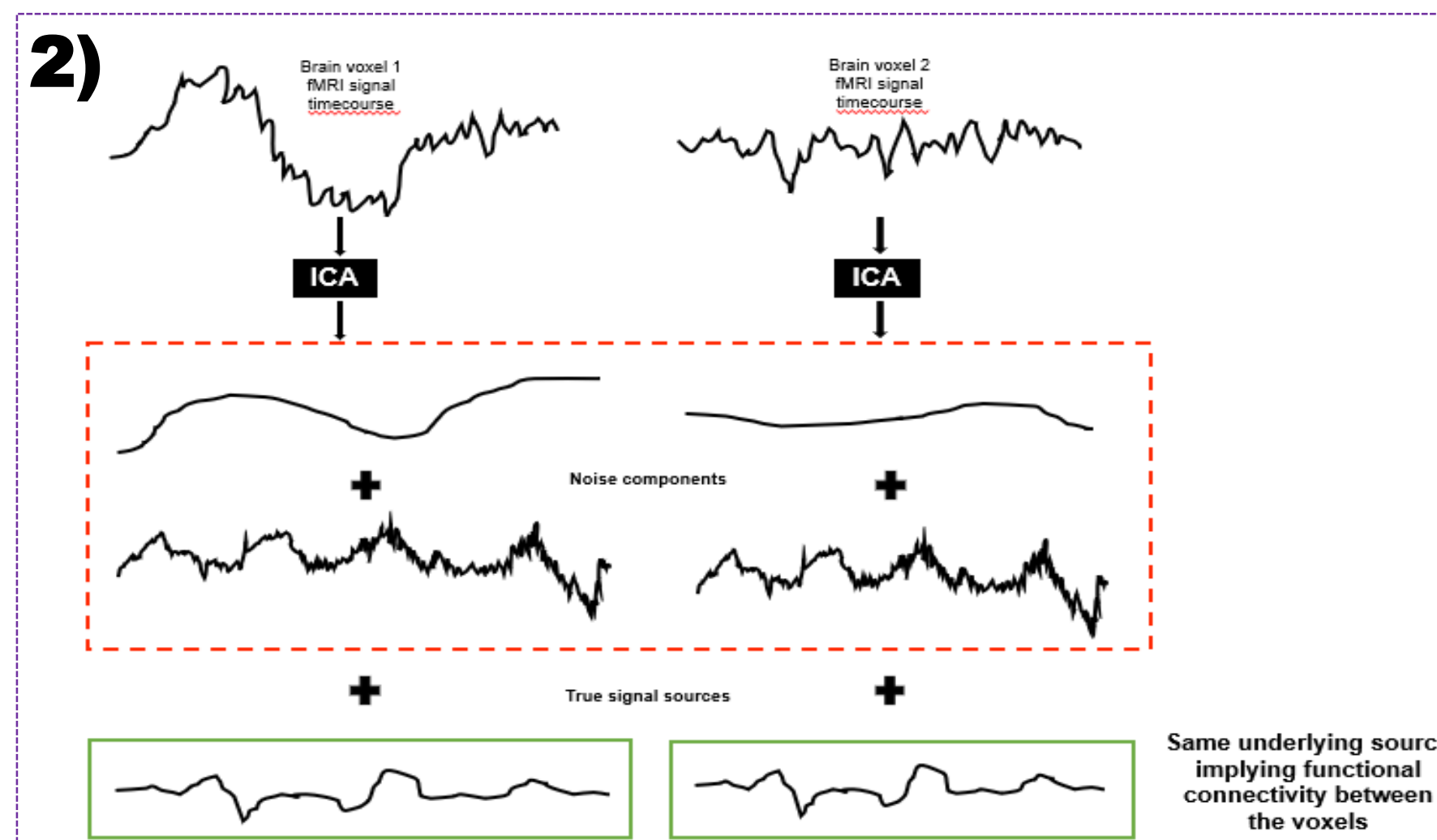| Feature	Seed Region	Level Of Processing By Dynamic Network	Brain Areas Dynamically Interacting With Seed
Speech	IC1 Auditory	Further Speech, Language & Memory, and High-Level Learning & Moral Perception	Parts of Occipital, Temporal, Parietal, Frontal Lobes and Caudate Nucleus
Faces	IC1 Auditory	Further Speech, Language, Visual & Memory, and High-Level Emotion & Attention	Parts of Occipital, Temporal Lobes and Cingulate regions
Speech	Right FFA	Further Speech, Language, Visual & Memory, and High-Level Social Interpretation	Parts of Occipital, Temporal, Parietal and Frontal Lobes
Faces	Right FFA	Further Visual, Faces & Memory, and High-Level Attention Switching	Parts of Occipital, Parietal & Frontal Lobes

FFA – Fusiform Face Area

4 The Complete Hierarchical Pathway For Processing Simple Elements Of Complex Naturalistic Stimuli

High-Level Processing – Cognitive & Emotion

Low-Level Processing – Sensory Perception

Method?	GLM	ICA	GLM/ICA+ GLM_dFC
Responds Directly to Specified Basic Features of Stimuli (faces/speech)?	✓	✗	✓
Hierarchical?	Low-level regions	Incomplete	Complete
Static or Dynamic Connectivity Between Regions?	Static	Static	Static+ Dynamic