Supplementary Information

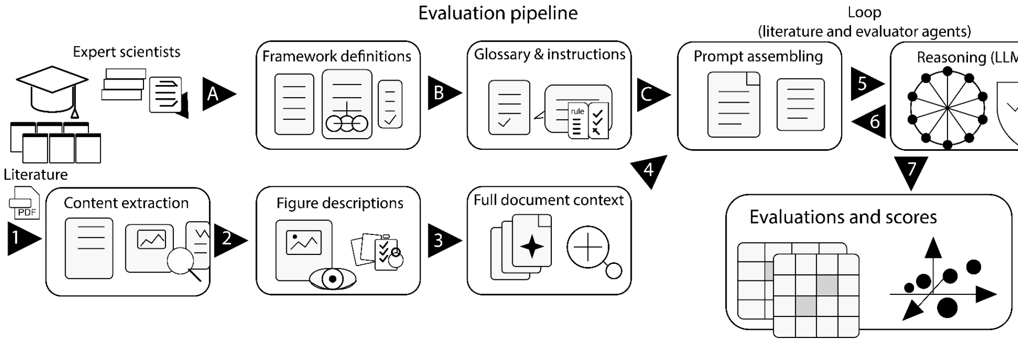
Ontology-constrained multi-LLM scoring of hypothesis support in the predictive processing literature

Hamed Nejat, Alexander Maier, Jesse Spencer-Smith, and André M. Bastos

Supplementary Information

Supplementary Fig. S1

Supplementary Fig. S1: The evaluation pipeline flows from left to right in two independent streams (A to B to C and 1 to 2 to 3). The A to B to C pathway establishes the instructions, canonical glossary, and prompt for the models. The 1 to 2 to 3 pathway ingests the paper and combines figures with text to provide a single text object for the models. Steps 5 and 6 loop between models and papers until all evaluations are completed. The final step 7 quantifies and visualizes the evaluations.



Supplementary Tables

Factor Number	Factor Name	Definition	Context Scope
1	Subtractive Inhibition (SST)	Linear input suppression via somatic inhibition (Somatostatin-mediated).	LO+GO
2	Divisive Inhibition (PV)	Multiplicative gain reduction (Parvalbumin-mediated).	LO+GO
3	Inhibition (GABA)	Chloride-mediated inhibition for prediction suppression.	LO+GO
4	Habituation to Sequence	Habituation suppresses local oddball response relative to a novel local oddball.	LO
5	Synaptic Depression (Adaptation)	Passive fatigue of synaptic efficacy due to repetition of stimulus.	LO

Factor Number	Factor Name	Definition	Context Scope
6	Activity Suppression	Reduction in firing rates for expected (predictable) stimuli.	LO+GO
7	Selective Sharpening	Signal-to-noise increase for predictable stimuli, where noise is selectively suppressed to highlight relevant information.	LO+GO
8	Alpha/Beta Mediated Suppression	Low-frequency bands (8-30Hz) associated with predictions, inhibiting prediction error signals.	LO+GO
9	VIP-Mediated Disinhibition	VIP-mediated inhibition of SST/PV neurons, leading to disinhibited pyramidal activity during prediction error.	LO+GO
10	Precision Weighting (Gain)	Top-down amplification of error units, leading to disinhibited gain in response to attended or highly precise stimuli.	LO+GO
11	E/I Balance Shift	Dynamic adjustment toward higher inhibition for predictable stimuli, leading to suppressed neural firing.	LO+GO
12	Omission Response	A generated internal signal due to absence of expected input	LO+GO

Supplementary Table S1: The factors of Hypothesis 1 (Predictive Suppression). LO = local oddball. GO = global oddball.

Factor Number	Factor Name	Definition	Context Scope
13	Feedforward Deviance Detection	Detection of mismatch signals that explicitly propagate in the feedforward (ascending) direction to higher cortical areas.	LO+GO
14	Feedforward AMPA	Fast excitatory drive mediated by AMPA receptors, specifically conveying prediction-error signals in the feedforward direction.	LO+GO
15	Feedforward NMDA	Voltage-dependent amplification (bursting) of error signals, facilitating their robust feedforward propagation through the hierarchy.	LO+GO
16	Feedforward Ascending Gamma	Rhythmic synchronization (30-90Hz) that temporally packages prediction-error signals for efficient feedforward transmission.	LO+GO
17	Absence of Feedback Error	The functional requirement that the prediction-error signal be feedforward-directed, distinguishing it from local or feedback signals.	LO+GO

Factor Number	Factor Name	Definition	Context Scope
18	Feedforward Non-local Supragranular Activity (L2/3)	Error-signaling neurons in Layers 2/3 projecting into the next area, demonstrating feedforward signal propagation.	LO+GO
19	Feedforward Non-local Granular Activity (L4)	The arrival of prediction error signals in Layer 4, non-local representing the canonical entry point for feedforward propagation into the cortical column.	LO+GO
20	Feedforward Non-local Directed Connectivity	Directional measures (Granger Causality/Transfer Entropy) confirming the directed feedforward propagation of prediction error from lower to higher areas.	LO+GO
21	Feedforward Non-local Activation	Functional activation patterns specifically tracing the feedforward propagation path through the hierarchy.	LO+GO
22	Ascending Latency Shift	Systematic increases in response latency that characterize the feedforward propagation of prediction error through successive levels of the hierarchy.	LO+GO
23	Feedforward Error Propagation	Explicit experimental evidence that the prediction error signal is transmitted primarily via feedforward propagation pathways.	LO+GO
24	Subcortical Feedforward Relaying	Relaying or generation of prediction error signals by subcortical structures (Thalamus/BG), initiating or sustaining their feedforward propagation to the cortex.	LO+GO

Supplementary Table S2: The factors of Hypothesis 2 (Feedforward Error Propagation)

Factor Number	Factor Name	Definition	Context Scope
25	Canonical Microcircuit Ubiquity	The ubiquitous presence of the L2/3 Error and L5/6 Prediction motif repeating across most or all levels of the cortical hierarchy.	LO+GO
26	Hierarchical Mechanism Invariance	The ubiquitous nature of the predictive coding mechanism, functioning similarly in the hierarchy from V1 to PFC.	LO+GO
27	Hierarchical Activity Ubiquity	The ubiquitous presence of prediction-error activity, detectable across all or most levels of the system's brain hierarchy.	LO+GO
28	Hierarchical CSD Ubiquity	The ubiquity of current source density profiles, which show consistent laminar patterns across most or all hierarchical levels.	LO+GO

Factor Number	Factor Name	Definition	Context Scope
29	Cross-Scale Hierarchical Ubiquity	The ubiquity of effects observable across scales (single units to LFP) throughout most levels of the cortical hierarchy.	LO+GO
30	Hierarchical Presence (V1-PFC)	The ubiquity of the mechanism across all levels of the hierarchy, such as low-level (V1), mid-level (V4), and high-level (PFC) areas.	LO+GO
31	Cross-Modal Ubiquity	Presence of the mechanism across multiple sensory modalities (visual, auditory, somatosensory) throughout the hierarchy.	LO+GO
32	Interspecies Hierarchical Ubiquity	Conservation of the hierarchical predictive coding mechanism across different species (e.g., mouse vs. primate).	LO+GO
33	Temporal Stability of Ubiquity	The consistent and non-transient presence of these mechanisms across the hierarchy over long recording sessions.	LO+GO
34	Hierarchical Order Stability	Evidence that the predictive mechanism is ubiquitous and not localized to a single hierarchical pole.	LO+GO
35	Population-Wide Ubiquity	Consistency of the mechanism across diverse neural populations and cell types throughout the hierarchy.	LO+GO
36	State-Independent Ubiquity	Presence of the mechanism across different brain states (e.g., wakefulness, sleep, anesthesia) throughout the hierarchy.	LO+GO

Supplementary Table S3: The factors of Hypothesis 3 (Ubiquity)

Term/Context	Description	Definition (notation)
Oddball	A surprising event, often a mismatch	$S = \{B\}$ given $E[S] = \{A\}$
Local Oddball (LO)	An oddball that is immediate or short-term, often confounded by low-level adaptation mechanisms.	$S = \{AB\}$ given $E[S] = \{AA\}$
Global Oddball (GO)	An oddball that is not LO, often contextual, that is not caused by adaptation mechanisms.	$S = \{AA\}$ given $E[S] = \{AB\}$

Supplementary Table S4: Contexts ; $S=\{.\}$ represents the sensory input, $E[S]$ represents the expected sensory input. When $S=\{A\}$ and $E[S] = \{A\}$; the prediction error is zero (match). When $S=\{B\}$ and $E[S] = \{A\}$; the prediction error is non-zero (mismatch). LO and GO differ by the temporal scale of expectation.

#	Study	Short Description
1	Attinger et al., 2017[60]	Integrating non-visual (motor) inputs into V1 to generate mismatch signals during locomotion.
2	Bakhtiari et al., 2021[61]	Alignment between deep neural networks and biological vision across different predictive goals.
3	Bastos et al., 2012[14]	Canonical microcircuits for predictive coding; proposing distinct roles for superficial and deep layers.
4	Bastos et al., 2020[24]	Laminar and directional flow of prediction/error signals in primate visual and prefrontal areas.
5	Bekinschtein et al., 2009[62]	Neural markers of conscious perception using hierarchical auditory oddball tasks (fMRI/EEG).
6	Chao et al., 2018[26]	Global distribution of prediction errors across the primate brain using large-scale ECoG mapping.
7	Friston et al., 2010[10]	The Free Energy Principle: a unified framework for brain function and biological self-organization.
8	Furutachi et al., 2024[63]	Cooperative thalamocortical circuit mechanism for sensory prediction errors.
9	Garrett et al., 2020[64]	Emergence of prediction errors in the mouse visual cortex for surprises in sequence patterns.
10	Greedy et al., 2022[65]	Uses a new model, Bursting Cortico-Cortical Networks to approximate error backpropagation in a biological network of neurons.
11	Hertag et al., 2020[66]	Role of inhibitory interneuron types (PV and SST) in shaping cortical prediction errors.
12	Jiang et al., 2024[67]	Integrating hierarchical predictive coding for sequence learning.
13	Keller et al., 2012[68]	Sensorimotor prediction errors in V1; neurons responding to mismatches between movement and visual flow.
14	Keller et al., 2018[23]	Review of evidence of predictive processing and its implementation in mammalian cortical circuits.
15	Kiebel et al., 2008[69]	Hierarchical temporal dynamics; suggesting slower dynamics represent higher-level predictions.
16	Lao et al., 2023[70]	Provides evidence that top-down feedback is necessary for generating prediction error signals from omitted-tones.
17	Lee et al., 2025[71]	Computational modeling of PV/SST/VIP inhibitory interneurons and their dynamics during predictive processing
18	Mikulasch et al., 2023[72]	How predictive coding might utilize dendritic error computations
19	Nejad et al., 2025[73]	A self-supervised computational learning theory that aligns with the layer-specific neuronal observations in primary visual cortex
20	Payeur et al., 2021[74]	Burst-based firing enables the multiplexing of feedforward and feedback signals for predictive coding.
21	Rao et al., 2024[75]	Generalized predictive coding and sensorimotor theory of neocortex
22	Rao&Ballard, 1999[59]	Seminal model of hierarchical predictive coding explaining extra-classical receptive field effects in V1.
23	Sacramento et al., 2018[76]	Dendritic model explaining how neurons learn top-down predictions via local error signals.

#	Study	Short Description
24	Spratling et al., 2008[77]	PC-BC model: implementing predictive coding within a biased competition framework for object recognition.
25	Spratling et al., 2010[78]	Predictive coding as a model of response properties in cortical area V1
26	Srinivasan et al., 1982[7]	Predictive coding in the retina; earliest formalization of removing redundancy from natural images.
27	VanDerveer et al., 2021[79]	Somatostatin-Positive interneurons in neuro-oscillatory deficits
28	Wacongne et al., 2012[80]	Spiking neural network reproducing the auditory mismatch negativity (MMN) through predictive mechanisms.
29	Wacongne et al., 2011[52]	MEG study showing the human brain detects violations of abstract hierarchical rules in sound sequences.
30	Westerberg et al., 2025[34]	A recent study using Multi-Area, High-Density, Laminar Neurophysiology (MaDeLaNe) recordings in mice and monkeys to investigate global-local oddballs
31	Yamins et al., 2014[81]	Using goal-driven deep hierarchies (HCNNs) to predict neural responses across the visual cortex.

Supplementary Table S5: A total of 31 papers were considered in the current work. 25 papers were chosen as representative of the predictive coding literature, based on Westerberg et al.[34] and span contributions ranging across theoretical, empirical, and computational sub-fields of predictive coding (PC). Additional papers (Bakhtiari et al., 2021; Greedy et al., 2022; Payeur et al., 2021; Sacramento et al., 2018; Yamins et al., 2014) were included as they represent an adjacent field of computational neuroscience where alternative mechanisms for prediction error propagation have been proposed. An additional paper, Garrett et al., 2020, was also included to consider predictive coding mechanisms related to omissions, as these responses may be partially overlapping or distinct from classical PC mechanisms.

Model Name (handle-mlx)	Size	Release Date and info
gemma-3-27b-it	27B	Google DeepMind, 2025-03
gemma-4-31b-it	31B	Google DeepMind, 2026-04
deepseek-r1-distill-llama-70b	70B	DeepSeek-AI / Meta AI (Llama Base), 2025-01
gpt-oss-claude-4.5-sonnet	20B	Community Distillation (Teacher: Claude 4.5), 2026-03
mistral-nemo-12b-thinking	12B	Mistral AI & NVIDIA, 2024-07
olmo-3-32b-think	32B	Allen AI (Ai2), 2025-12
phi-4-reasoning-plus	14B	Microsoft, 2025-03
qwen3-14b-gemini-3-pro	14B	Qwen (Community Fine-tune), 2025-12
qwen3-14b-claude-4.5-sonnet	14B	Qwen (Community Fine-tune), 2025-12
qwen3.5-40b-claude-4.5-opus	40B	Qwen (Community Fine-tune), 2026-01

Supplementary Table S6: Open-weight LLMs used in this work. All models were running with MLX-LM (the python package for running LLMs locally on Apple's silicon hardware, M-series).