Alpha/Beta - Gamma Oscillatory Dynamics as Neural Markers of Predictive Processing: Investigating feedback and feedforward processes in a social inference task

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Abstract

This work investigates whether EEG oscillations, particularly in the alpha/beta and gamma frequency bands, can be used to distinguish feedback and feedforward processes proposed by the Predictive Processing (PP) framework. More specifically, it examines whether alpha and gamma activity in posterior, particularly parieto-occipital, regions show patterns consistent with their proposed roles in feedback and feedforward signaling. Despite strong theoretical support for PP, establishing clear links between its computational principles and measurable neural dynamics remains an open challenge. Building on evidence from research on information flow within the laminar organization of the cortex, sensory neuroscience and experimental studies of predictive cognition, this paper develops a provisional theoretical synthesis of alpha/beta and gamma dynamics in predictive processing (Bastos et al., 2012). This synthesis is used to formulate a proposed model of the expected oscillatory dynamics of feedback and feedforward processing and later shows how it can be applied in a social inference task developed by Ece Kurnaz and colleagues (work in progress). This paper therefore proposes (1) a theoretically grounded model of alpha/beta and gamma dynamics, and (2) a presentation of a task for evaluating that model against collected data.

Keywords

Alpha/Beta oscillations, Gamma oscillations, Laminar studies, Neural markers, Predictive processing, Social inference

1 Introduction

Predictive processing (PP) proposes that perception and cognition depend on the continuous generation and updating of predictions about incoming sensory information (Clark, 2013; Hodson et al., 2024). These processes are commonly described within a hierarchical architecture, in which information is exchanged between cortical levels through ascending feedforward (FF) and descending feedback (FB) signaling.

Although PP has substantial theoretical influence, its proposed neurophysiological implementation remains difficult to identify. Neural responses to expected and unexpected stimuli can be interpreted as consequences of predictive processing, but may also arise from adaptation, attention, or stimulus-driven responses (Walsh et al., 2020; Hodson et al., 2024). This problem becomes particularly relevant for EEG, which measures the aggregate activity of large neuronal populations and cannot directly isolate cortical layers or individual FF and FB pathways.

The present paper therefore examines whether alpha- and gamma-band oscillations can provide population-level markers of processes proposed by PP. Rather than assuming a direct correspondence between frequency bands and functions, we first consider the cortical organization of FF and FB signaling and its relationship to oscillatory activity, before deriving provisional predictions that can be tested using EEG.

2 Theoretical synthesis

PP describes perception as inference within a hierarchical generative model. Higher cortical levels represent increasingly abstract and temporally extended regularities, while lower levels are more closely related to the processing of incoming sensory information. Within this hierarchy, descending signals provide predictions or contextual constraints, while ascending signals transmit sensory information and mismatches that can influence the generative model which generates the predictions (Clark, 2013; Hodson et al., 2024). However, the extent to which this computational organization corresponds to a specific neural architecture remains unresolved.

The cortical laminar organization provides one possible mechanistic basis for such hierarchical communication. The mammalian neocortex contains six principal layers with characteristic patterns of connectivity. Classical anatomical descriptions associate FF projections primarily with superficial layers (L 2/3), which preferentially target middle cortical layers, particularly layer 4, whereas FB projections are more strongly associated with deep layers (L 5/6) and have broader terminations that generally avoid layer 4 (Bastos et al., 2012; Vezoli et al., 2021). Bastos et al. (2012) incorporated this organization into a proposed canonical microcircuit for predictive coding.

However, it is important to note, that FF and FB signaling cannot be reduced to one superficial FF pathway and one deep FB pathway. Vezoli et al. (2021) build on a line of work on a dual counterstream architecture containing both superficial and deep pathways, including a substantial superficial FB pathway and evidence for deep layer FF projections. Different feedback pathways also differ in their spatial range and interactions with local circuitry. Consequently, descending signaling should not

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simply be equated with the transmission of predictions; it may support several functional roles within recurrent cortical processing.

Despite the caveats, there is strong coherence in the signature oscillatory frequency with which FF and FB pathways typically operate. Bastos et al. (2012) proposed a relationship between PP circuitry and frequency-specific activity, with gamma activity preferentially associated with superficial cortical processing and alpha/beta activity with deeper cortical layers. Invasive recordings have provided evidence for this spectrolaminar organization in which gamma-band power peaks in superficial layers, particularly 2/3, whereas alpha- and beta-band power is stronger in deeper layers, particularly 5/6 (Mendoza-Halliday et al., 2024). Vezoli et al. (2021) similarly linked the anatomical organization of cortical communication to similar characteristic frequency ranges.

This anatomical and oscillatory distinction is complemented by a functional one: FF signaling is generally associated with driving excitatory inputs, whereas FB signaling is proposed to exert an overall suppressive or inhibitory influence on lower-level populations, although it can also have driving and modulatory effects depending on context (Bastos et al., 2012). Together, these anatomical, spectrolaminar and functional distinctions provide a possible chain of reasoning which can help the interpretation of hierarchical communication in population-level oscillatory activity. However, this chain does not establish that scalp-recorded gamma directly represents FF signaling or that alpha/beta directly represents FB signaling. Cortical communication is recurrent, multiple neuronal populations contribute to each oscillatory signal, and the same frequencies can be modulated by attention, sensory processing, and other cognitive processes. Indeed, recent work has explicitly challenged a simple oscillatory division in which alpha/beta represents predictions and gamma represents prediction errors, emphasizing the importance of transient and context-dependent dynamics (Vinck et al., 2025).

Alpha and gamma nevertheless provide useful candidate signals at the population level. Alpha activity has been associated with functional inhibition and gating, with increased alpha power often accompanying reduced processing of task-irrelevant information and alpha suppression accompanying engagement of task-relevant sensory regions (Jensen & Mazaheri, 2010). Gamma synchronization, in contrast, is frequently associated with localized sensory processing and neuronal communication (Fries, 2015). Their complementary functional properties, together with their proposed laminar organization, provide a basis for investigating different stages of hierarchical processing without assuming that either frequency is computationally specific.

3 Predicted dynamics / hypotheses

The literature on predictive-processing tasks provides several provisional predictions primarily concerning oscillatory dynamics in posterior sensory regions. First, expectation formation and maintenance should be accompanied by modulation of pre-stimulus alpha/beta activity in posterior regions. Increased alpha/beta power has been reported before expected sensory events, including implicitly learned face sequences and probabilistic attentional cues (Roehe et al., 2021; Li et al., 2023).

Second, unexpected stimuli may produce greater post-stimulus alpha event-related desynchronization (ERD) in posterior regions than expected stimuli, following from the functional-gating interpretation of alpha, in which reduced alpha activity is associated with increased engagement of sensory processing (Jensen & Mazaheri, 2010).

Third, greater mismatch between expected and observed information may be accompanied by increased post-stimulus gamma activity in posterior regions. This follows from predictive-coding accounts linking higher-frequency activity to ascending sensory processing and from empirical studies reporting stronger gamma responses to unexpected or mismatching stimuli (Bastos et al., 2012; Strube et al., 2021; Roehe et al., 2021).

Taken together, these predictions suggest a temporal sequence within posterior sensory regions: low-frequency activity may be particularly informative during the formation and maintenance of expectations, while post-stimulus alpha and gamma dynamics may reflect subsequent processing and updating.

These hypotheses remain provisional and are intended to provide falsifiable predictions for the empirical analysis. Frontal regions may serve as potential sources of top-down modulation of these posterior dynamics, but the primary predictions concern posterior activity.

4 Empirical approach

In a social inference task developed by Ece Kurnaz and colleagues (personal communication, 2026), each trial begins with a probability cue indicating the likelihood that a target object is present in a subsequently revealed scene; participants judge object presence as the target region gradually unblurs. The cue is predictive of the correct answer on 70% of trials, yielding prior-congruent and prior-incongruent trials, alongside a neutral condition in which the cue carries no informative bias. The social inference task follows an analogous structure: a prior characterizing the relationship between two depicted individuals (e.g., friends, a positive-valence prior) precedes a binary judgment (e.g., whether they will help each other) made as the scene gradually unblurs; as in the visual task, the prior is predictive of the outcome on 70% of trials, with an analogous neutral condition. This parallel structure allows the visual task to serve as a lower-level perceptual control, isolating effects of social content from the probabilistic-cueing and gradual-evidence-accumulation structure shared by both tasks.

5 Discussion / Outlook

The framework that is being developed here provides a possible route from predictive processing to measurable EEG dynamics. PP proposes hierarchical exchange between ascending and descending information streams; cortical anatomy provides partially distinct laminar pathways through which these signals interact; and invasive recordings indicate that these compartments exhibit characteristic oscillatory dynamics. Alpha and gamma can therefore be treated as candidate population-

level markers through which aspects of hierarchical processing may become observable.

This chain should not, however, be interpreted as a direct mapping between computational function, cortical pathway and frequency band. The multiplicity of FF and FB pathways, recurrent cortical dynamics, and the sensitivity of alpha and gamma to attention and sensory processing all constrain such an interpretation. The recent emphasis on transient and context-dependent dynamics further suggests that oscillatory activity alone may not provide a complete account of predictive processing (Vinck et al., 2025).

The value of the proposed framework therefore lies in constraining interpretation rather than providing a direct anatomical readout. By linking PP to cortical architecture and spectrolaminar dynamics, it becomes possible to formulate more specific predictions about population-level EEG activity than would be possible from changes in alpha/beta or gamma power alone. Subsequent work should test whether these predicted dynamics are observable during social predictive processing and, in doing so, assess how far EEG oscillations can usefully inform the proposed neurophysiological mechanisms of PP.

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