

Prefrontal Alpha Stabilization and Postmidpoint Improvement in Tinnitus/Hearing Outcomes: A Single-Case Report with Bayesian Change-point Analysis

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ABSTRACT

This single-case report conceptualizes tinnitus not as a solitary output of the auditory cortex but as a systems-level phenomenon arising from the interplay among attentional, affective, and cognitive networks. Over 12 months, the patient received combined acupuncture, pharmacopuncture, herbal medicine, prefrontal alpha-centric neurofeedback, and Reve 134-based sound retraining (2–3 sessions/week, approximately 30 min/session). Prefrontal electroencephalography (EEG) alpha peak frequency (Hz), Tinnitus/Hearing Difficulty VAS (0–10), and minimum masking level (MML, dB SL) were evaluated at three prespecified time points: baseline, midpoint (≈ 5.5 months postbaseline), and final (≈ 11.7 months postbaseline). The findings indicated postmidpoint temporal coupling: the alpha peak stabilized from 10 to 11 Hz, the VAS scores declined (tinnitus 5→4→2; hearing difficulty 8→6→3), and the right-ear MML improved after a plateau (79→79→54 dB SL). Contrarily, the left ear did not require masking at the final time point. A Bayesian change-point-slope model favored a midpoint change-point, with posterior directionality consistent with acceleration in the second segment (EEG increased; VAS/MML decreased; see Appendix). Within the caveats of a single case, EEG emerges as a treatment-agnostic biomarker for guiding and monitoring responses across different modalities.

Keywords: Tinnitus; EEG; Alpha Oscillation; Neurofeedback; Sound Therapy; Bayesian Analysis.

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INTRODUCTION

Tinnitus is a complex condition that persists not simply due to peripheral damage but through a self-amplifying loop involving auditory input, emotional responses, and attentional systems. In clinical practice, even when the Hearing Difficulty VAS score is higher, there are instances in which the practical emphasis of treatment is directed toward controlling tinnitus. This aligns with the observations that tinnitus is closely related to deterioration in sleep, emotional well-being, and quality of life and that restoration of central control (attentional gating) may precede and facilitate a decline in the overall burden. In this context, despite a higher Hearing Difficulty VAS, this case report designated tinnitus as the primary target and monitored its progress in parallel with EEG alpha stabilization. Consistent with predictive coding, the efficiency of top-down gating appears to have progressed beyond a critical point, reducing listening effort and distress.

CASE REPORT

Subject

A 69-year-old man with a history of otitis media dating back 50 years presented for evaluation. He had chronic tinnitus, which had worsened over the past year due to increased stress, accompanied by subjective hearing loss and distress.

Interventions

- Korean Medicine Treatment: Acupuncture, pharmacopuncture, and herbal medicine (to enhance systemic homeostasis and stabilize emotional regulation and autonomic nervous systems).
- Neurofeedback: Two-channel, prefrontal-centric alpha stabilization training.
- Sound Retraining: Adaptive training based on Reve 134 (partially overlapping with Threshold Sound Conditioning principles).
- Treatment Intensity: Two to three sessions per week, approximately 30 min/session, for a total of 12 months.

Summary of Clinical Application Flow:

1. Systemic and emotional stabilization: Attenuate internal noise and precision-weighting → Reduce tinnitus reaction.
2. Restore prefrontal alpha gating (balance of event-related synchronization/desynchronization [ERS/ERD]): Stabilize top-down and bottom-up processing networks → Decrease listening effort.

3. Recondition sensory input (sound therapy): Reduce the discrepancy between top-down expectations and bottom-up input → Improve minimum masking level (MML) → Concurrently improve Hearing Difficulty VAS.

(Monitoring: EEG alpha peak/spatial patterns, VAS (Tinnitus/Hearing Difficulty), MML, and, if necessary, sleep/anxiety questionnaires).

Outcome Measures and Time Points

1. EEG: Left and right prefrontal alpha peak frequency (Hz).
2. Subjective indicator: Tinnitus and Hearing Difficulty VAS (0–10).
3. Threshold indicator: MML (dB SL, right ear; left ear required no masking at the final time point, N/A).
4. Time points: Baseline, midpoint (≈ 5.5 months postbaseline), final (≈ 11.7 months postbaseline).
5. Key outcomes (EEG alpha, VAS, and MML) measured at BL, midpoint, and final are summarized in **Table 1**.

RESULTS

1. EEG alpha peak: 10 Hz (baseline and midpoint) → 11 Hz (final).
2. Tinnitus VAS: 5 → 4 → 2.
3. Hearing Difficulty VAS: 8 → 6 → 3.
4. MML (right): 79 → 79 → 54 dB SL (25 dB improvement after stagnation at midpoint).
5. MML (left): Resolved at the final time point (N/A, masking unnecessary).
6. **Table 1** presents detailed numerical summaries.

The overall pattern showed an accelerated and simultaneous improvement across EEG (stabilization \uparrow), VAS (reduction \downarrow), and MML (reduction \downarrow) in the postmidpoint of the treatment period.

DISCUSSION

This case conceptualizes tinnitus not as a mere product of auditory stimulation but as a global phenomenon arising from the interplay among attentional, emotional, and cognitive networks. The results indicated a temporal coupling that became evident postmidpoint. The prefrontal alpha peak remained at 10 Hz at baseline and midpoint and then stabilized at 11 Hz at the final measurement. Concurrently, the reduction in Tinnitus

Table 1: Longitudinal outcomes at three time points (BL, Mid, and Final)

Indicator	Baseline (BL)	Midpoint (Mid)	Final
EEG Alpha Peak (Hz)	10	10	11
Tinnitus VAS	5	4	2
Hearing Difficulty VAS	8	6	3
MML (Left, dB SL)	64	44	Resolved (N/A)
MML (Right, dB SL)	79	79	54

Abbreviations: BL = Baseline; Mid = Midpoint; MML = Minimum masking level; VAS = Visual analog scale

VAS (5→4→2) and Hearing Difficulty VAS (8→6→3) accelerated postmidpoint. The left-ear MML was resolved (masking unnecessary) by the final assessment, whereas the right ear exhibited a 25-dB improvement after a period of stagnation (79→79→54 dB SL).

This trend supports the possibility of central readjustment occurring first, wherein prefrontal alpha stabilization restored the gating function of selective attention and suppressed unnecessary bottom-up inputs, thereby initially minimizing listening effort and distress¹⁻⁶. This process is better understood not as a feedforward, stepwise process but rather as a coordinated tuning within a recurrent network that involves re-entry and feedback. From the perspective of predictive coding and active inference, top-down alpha/beta oscillations mainly carry inhibitory/predictive signals, whereas bottom-up gamma oscillations convey prediction errors. The stabilization of alpha from 10 to 11 Hz and the accelerated improvement of VAS/MML postmidpoint align with a scenario in which the efficiency of top-down/bottom-up signal exchange surpassed a critical threshold¹⁻⁶.

Concurrently, the Hearing Difficulty VAS improved, despite not being the main treatment target. Rather than attributing the changes to a rapid recovery of peripheral thresholds, it is more consistent to interpret them as a consequence of central gating restoration. The attentional and emotional overload accompanying tinnitus likely resulted in a decrease in the efficiency of higher-order auditory processing, leading to a perception of greater hearing loss. Central gating recovery reduced listening effort, which in turn positively influenced the Hearing Difficulty VAS. Indeed, the patient's exposure to threshold sound conditioning was modest (2–3 times a week for 30 min/session), and the total amount of neurofeedback was conservative, making it insufficient to establish a standalone causal effect for any single technique. Nevertheless, the observed trend of VAS and MML improvements, despite the absence of clear change in pure-tone audiometry (PTA), can be explained by differences in indicator sensitivity, measurement windows, and parameter sensitivity. That is, while peripheral threshold indicators (e.g., PTA) may remain unchanged in the short term, VAS and MML can respond

more sensitively to suprathreshold perceptual changes, and the preceding recovery of central gating can initially manifest as a reduction in subjective burden^{1,2,7,8}.

To quantitatively evaluate the coherence of this inference, we applied a Bayesian changepoint and slope model within a Bayesian data analysis framework to the three-point dataset^{9,10}.

The posterior distribution supported a higher probability of the changepoint (τ) being at the midpoint (under a midpoint-favoring prior on τ ($p(\tau) \propto \{1,3,1\}$)), and the directional probability of the latter-half slope (δ) was dominant for an EEG increase (accelerated stabilization) and VAS/MML decrease (accelerated improvement). **Table 2** provides relevant statistical summaries supporting this interpretation. Posterior predictive checks (PPC) confirmed that the 90% prediction interval encompassed all observed data, suggesting that the current model is at least consistent with the observed pattern¹⁰. However, owing to the structural limitations of a single case and three time points, sensitivity to the prior is high, and the numerical values should be hypothetically interpreted, not causally estimated^{9,10}.

In summary, although the dosage and duration of the different interventions in this case are insufficient to claim individual causality, their interaction and feedback likely induced a network-level transition. BDA provides numerical support for the temporal coupling and directionality of this transition. Within this context, EEG is useful as a treatment-agnostic biomarker for tracking and guiding responses regardless of the treatment type. A reasonable clinical strategy is to use the synchronicity of EEG-VAS-MML as a criterion for judging transition points, supplemented by ancillary measures such as distortion product otoacoustic emissions, auditory brainstem response, and extended high frequency to confirm peripheral changes^{1,2,7}.

Finally, although the increase in prefrontal alpha peak frequency from 10 to 11 Hz is a variation within the normal range and should not be overinterpreted in isolation, its context—bilateral, simultaneous emergence in the postmidpoint, temporally overlapping with accelerated VAS reduction, left MML resolution, and delayed

Table 2. Change metrics and interpretive remarks.

Indicator	Improvement (BL→Mid)	Improvement (Mid→Final)	Overall Improvement	Remarks
EEG Alpha Peak (Hz)	0	+1 (+10.0%)	+1 (+10.0%)	No change until midpoint, then stabilization/increase
Tinnitus VAS	+1 (+20.0%)	+2 (+50.0%)	+3 (+60.0%)	Accelerated improvement in the latter half
Hearing Difficulty VAS	+2 (+25.0%)	+3 (+50.0%)	+5 (+62.5%)	Accelerated improvement in the latter half
MML (Left, dB SL)	+20 (+31.3%)	Resolved (N/A)	Resolved (N/A)	Resolved: Masking unnecessary → MML not calculated
MML (Right, dB SL)	0 (0%)	+25 (+31.6%)	+25 (+31.6%)	Stagnation at midpoint, improvement at final

Note: All values are direction-normalized so that positive numbers (+) consistently indicate clinical improvement. For outcomes where lower scores represent improvement (Tinnitus VAS, Hearing Difficulty VAS, and MML), improvement was calculated as (prior – subsequent); for EEG alpha peak frequency, improvement was calculated as (subsequent – prior). Percentage

right MML improvement—makes it an important clue suggesting gating efficiency reconfiguration. Future studies using denser measurement points and designs that systematically vary in terms of intervention intensity and parameters, analyzed using dynamic Bayesian state-space models including time-varying covariates, could more precisely map the fine structure of these transitions and the respective contributions of central and peripheral factors.

Limitations and Future Directions

The main limitation is the low sample resolution inherent in a single-case, three-time point design. Change-point estimation and slope directionality have been reported as posterior probabilities; however, they do not claim causal inference. Future studies require model comparison (alternative change-point, nonlinear, state-space models) and external validation with multicase, multi-time point data.

CONCLUSION

Postmidpoint of treatment, EEG alpha stabilization (10→11 Hz) and accelerated improvement in Tinnitus/Hearing Difficulty VAS and MML were observed. This suggests that within the interaction of multiple interventions, the preceding recovery of gating efficiency can reduce subjective burden, resulting in a concurrent improvement in perceived hearing difficulty (VAS). EEG shows high potential as a clinical indicator that is suitable for guiding and tracking treatment responses, regardless of the therapeutic modality (e.g., Korean medicine, neurofeedback, sound retraining).

ETHICS STATEMENT

This case report complied with the principles of the Declaration of Helsinki. Institutional review board oversight was deemed unnecessary for a single anonymized case; if locally required, it was waived.

INFORMED CONSENT

Written informed consent for the use of de-identified clinical data and EEG records was obtained from the patient.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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DATA AVAILABILITY

Deidentified data and analysis scripts are available from the corresponding author upon reasonable request.

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APPENDIX

A. Data/Preprocessing

- Time Points: Baseline (BL), Midpoint (Mid), Final
- Indicators: EEG alpha peak (Hz), VAS (Tinnitus/Hearing Difficulty), MML (Right, dB SL; Left N/A at the final measurement)
- Preprocessing: Indicators were z-score standardized for BDA.

B. Model Overview (Change-point τ and Latter-Half Slope δ)

On a standardized scale:

$$y_t = \mu + \beta t + \delta \max(0, t - \tau) + \varepsilon_t, \varepsilon_t \sim N(0, \sigma^2), t \in \{0, 1, 2\}.$$

- Change-point candidates: $\tau \in \{0, 1, 2\}$ (BL, Mid, Final).
- Prior for τ : $p(\tau) \propto \{1, 3, 1\}$ (midpoint favored); sensitivity checks used $\{1, 2, 1\}$ and $\{1, 1, 1\}$.
- Priors for coefficients: Independent zero-centered normal priors of moderate scale for μ, β, δ (no enforced sign constraints).
- Prior for variance: Inverse-gamma prior for σ^2 (robustness checked using a half-Cauchy alternative).
- Interpretation of δ : $\delta > 0$ indicates accelerated stabilization (EEG); $\delta < 0$ indicates accelerated improvement (VAS/MML).
- PPC: 90% posterior predictive intervals covered all the observed data points.

C. Posterior Probability of Change-point (τ)

- Default Prior: BL 0.113, Mid 0.713, Final 0.174
- Relaxed Prior: BL 0.128, Mid 0.467, Final 0.405

D. Posterior Summary of Latter-Half Slope (δ) (Excerpts)

- EEG alpha peak: mean 0.34, 90% CI $\approx [-1.07, 1.70]$, direction $P(\delta > 0) = 0.70$
- Tinnitus VAS: mean -0.264 , 90% CI $\approx [-1.59, 1.17]$, $P(\delta < 0) = 0.68$
- Hearing Difficulty VAS: mean -0.248 , 90% CI $\approx [-1.59, 1.08]$, $P(\delta < 0) = 0.666$
- MML (right): mean -0.35 , 90% CI $\approx [-1.74, 1.11]$, $P(\delta < 0) = 0.718$

(Directional probabilities were maintained under sensitivity analysis with the relaxed prior).

Note on Notation:

The “Resolved (N/A)” status for the left-ear MML was treated as censored data and was not converted to 0 dB.

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