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Structural Limits and Observable Benchmarks for Ganzfeld-tACS Computational Modeling: A Preregistered Boundary-Setting Study

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Research Article

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Structural Limits and Observable Benchmarks for Ganzfeld-tACS Computational Modeling: A Preregistered Boundary-Setting Study

Running title: Boundary-setting for Ganzfeld-tACS modeling

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Abstract

Background. Ganzfeld and tACS are candidate precision manipulations, but individual Jansen–Rit neural-mass (JR-NMM) inversion from scalp EEG is rarely gated by preregistered stopping rules.

Methods. Preregistered boundary-setting (seed=42) used synthetic recovery (N=50), a 3×3 full-band fidelity grid (n=10), and OpenNeuro ds005385, ds004902, and ds004148. Post-review diagnostics were a numerical Fisher information matrix (FIM), a 48-cell Welch grid, a hybrid aperiodic+oscillatory comparator, and Gaussian-copula transfer scores.

Results. Six kinetic parameters were practically unrecoverable under Welch PSD ($r<0.5$); only log G recovered ($r=0.917$). FIM is sloppy but does not isolate log G as the unique stiff direction. JR-only full-band r lost to a 1/f null, yet a hybrid model beat the aperiodic null (median $\Delta AIC=-76.7$; CV 10/10). Welch re-parameterization did not reproduce the original kill-gate (0/48 cells). Cross-dataset copula coverage was 65.2% (MMD $p=0.010$).

Conclusions. Individual kinetic profiling is practically unfeasible under Welch PSD. Oscillatory columns add validity once an aperiodic term is explicit. Usable outputs are observation-layer resting-state generators, not physiological subjects; ds004902 is sleep deprivation, not a Ganzfeld proxy.

Keywords. Jansen–Rit neural mass model; identifiability; Ganzfeld stimulation; tACS; Fisher information; Welch PSD; feature copula

1. Introduction

Homogeneous-field (Ganzfeld) stimulation and tACS are candidate manipulations of sensory and oscillatory precision. Before individual JR-NMM kinetics can be used as virtual subjects for in-silico Ganzfeld–tACS trials, inversion from scalp EEG must pass preregistered identifiability gates. This study sets those gates. The original boundary-setting claim treated kinetic unidentifiability as structural and full-band mismatch as 1/f dominance. The present text keeps the archived recovery and 3 × 3 numbers, but restricts the observation-operator scope and replaces "structural" with an operational/practical formulation wherever FIM eigenstructure does not uniquely support a kinetic fiber.

2. Methods

2.1 Observation operator

All kill-gates use Welch PSD as the observation operator. Conclusions apply to PSD-based inversion; multichannel CSD, coherence, and evoked-response features were not evaluated. Cross-spectral and source-space features were not evaluated and could alter identifiability. We did not perform a formal structural identifiability analysis via differential algebra.

2.2 Synthetic recovery and FIM

Synthetic recovery (N = 50, seed = 42) required r ≥ 0.5 and NRMSE ≤ 1.0. Post-review, a numerical FIM was computed at each θ_est on log10(G · |H(f)|²) over F_GRID (1–45 Hz, 177 bins) with log-parameter scaling for kinetics.

2.3 Copula and paradigm origin

The 70-subject copula was fitted on resting EC/EO recordings (ds005385, ds004148). The NS→SD probe (ds004902) indexes sleep deprivation, not homogeneous-field sensory deprivation. Transferability to Ganzfeld regimes was not quantified. No BIDS-formatted raw Ganzfeld EEG were available. The G-arm remained B-grade (sign-only literature priors).

2.4 Post-review grids

Welch windows {1, 2, 4, 8} s × overlaps {0, 0.25, 0.50, 0.75} × tapers {hann, hamming, blackman} were applied to the n = 10 mini records (48 combinations). Hybrid models fitted {offset, slope} (null), {log G} (oscillatory, kinetics pinned), and {offset, slope, log G, κ} (hybrid: PSD = aperiodic + κ · oscillatory) in log10-PSD space, with AIC/BIC and 5-fold frequency-bin CV.

3. Results

3.1 Synthetic recovery and FIM

Archived Table 1 is unchanged. Six kinetic parameters failed the conjunction; only log G passed (r = 0.917, NRMSE = 0.432).

FIM (new). Mean log-parameter FIM eigenvalues span many decades (sloppy map). The stiffest eigenvector loads on A (0.646) and a (0.657); log G loading on that direction is 0.013. This eigenstructure does not support the sentence "the kinetic subspace is near-singular and log G is the unique stiff direction." Combined with the recovery table, kinetic parameters are practically unrecoverable under our Welch PSD pipeline.

3.2 Full-band fidelity, Welch grid, hybrid comparator

The archived 3 × 3 remains: JR-family arms lost to the v2.2 aperiodic null (Δr < 0) under the original fitting scheme without explicit mixed aperiodic terms. On the same n = 10 records, 0/48 Welch combinations reproduced median r < 0.5 and median Δr < 0 when an oscillatory bump was allowed. Median r was typically 0.85–0.91. Hybrid versus null: median ΔAIC = −76.7, median ΔBIC = −70.3; CV favoured hybrid on all 10 records. Oscillatory columns therefore provide incremental validity when an explicit aperiodic term is included.

3.3 Observation-layer avatars and transfer

Archived within-table copula coverage 92.9%, IAF LOSO 94.3%, Berger 90% stand. Cross-dataset Gaussian-copula coverage ds005385 □ ds004148 = 65.2% (MMD permutation p = 0.010). Sleep-deprivation (ds004902) versus resting coverage is 71.6% and is not a Ganzfeld transfer score.

4. Discussion

Identifiability is a property of the observation operator. Under Welch PSD, the recoverable scalar in synthetic recovery is log G. A different EEG observable could in principle split some of the kinetic degeneracy without any change to the JR-NMM equations; that possibility is not evaluated here. Losing to a nested 1/f null when the oscillatory arm has no aperiodic term is expected if slope and offset dominate Pearson r. Hybrid AIC/CV shows that an oscillatory residual still pays for itself once 1/f is in the model. The copula is calibrated on resting EC/EO; ds004902 is normal-state to sleep-deprivation, not sensory deprivation.

5. Limitations

Cross-spectral and source-space features were not evaluated and could alter identifiability. We did not perform a formal structural identifiability analysis via differential algebra. No BIDS-formatted raw Ganzfeld EEG were available. The G-arm remained B-grade. Evoked-response features were not evaluated. Welch-grid oscillatory PSDs used a linearized/Lorentzian proxy when the JR transfer function was linearly unstable; archived 3 × 3 numbers remain the JR time-domain reference.

6. Conclusions

Under single-column/dual-column Jansen–Rit neural mass models with Welch PSD as the scalp EEG observation operator, individual-level kinetic profiling for Ganzfeld–tACS virtual subjects is practically unfeasible; whether alternative multivariate or transient EEG observables lift this ceiling remains open. Oscillatory columns are not ruled out once aperiodic structure is modelled explicitly. Usable outputs are observation-layer quantities that can serve as resting-state virtual cohort generators, not as physiological subjects; extension to Ganzfeld-conditioned cohorts requires a transferability step that this study does not perform.

Data and code availability

OpenNeuro datasets: ds005385 (https://doi.org/10.18112/openneuro.ds005385.v1.0.3), ds004902 (https://doi.org/10.18112/openneuro.ds004902.v1.0.8), ds004148 (https://doi.org/10.18112/openneuro.ds004148.v1.0.0). Download and analysis entry points: manuscripts/ganzfeld_tacs_boundary/code/download_openneuro.py and analysis_pipeline.py. Numerical products: manuscripts/ganzfeld_tacs_boundary/results/. Archived GTAC recovery and 3 × 3 tables remain under OPENNEURO DATAACCESS/Ganzfeld/outputs/gtac_virtual_subjects_v2/.

Ethics statement

No new human participants were recruited. Analyses used de-identified public OpenNeuro releases as described in the dataset records.

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Competing interests

The author declares that there are no competing interests.

Author contributions

K.W. conceived the study, performed the analyses, and wrote the manuscript.

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