The Hidden Fingerprint: Concatenated EEG States Outperform Reactivity Metrics in Biometric Identification

DREAMER Data Analysis Project

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Abstract

Background: In EEG analysis, "reactivity" (Stimulus minus Baseline) is a standard method intended to isolate event-related responses. However, this subtractive process may inadvertently remove stable subject-specific traits. **Objective:** To quantify the trade-off between signal reactivity and subject identifiability using the DREAMER dataset. **Methods:** We extracted spectral features from 23 subjects (18 trials each) using two distinct pipelines: (1) **Reactivity** ($\Delta = \mathrm{Stim} - \mathrm{Base}$) and (2) **Concatenation** ($[\mathrm{Stim}, \mathrm{Base}]$). We trained a Random Forest classifier to identify subjects and calculated Intraclass Correlation Coefficients (ICC) to assess trait stability. **Results:** The Reactivity method achieved a moderate accuracy of **47.34%**. In contrast, the Concatenation method achieved a superior accuracy of **95.89%** ($> 22\times$ chance level). Variance analysis revealed that raw spectral features possess high trait stability (ICC ≈ 0.70), which is largely destroyed during the subtraction process. **Conclusion:** EEG signals contain a robust "Neural Fingerprint" encoded in the raw spectral state. Preserving this baseline information, rather than subtracting it, is essential for high-performance biometric identification.

1 Introduction

The DREAMER dataset captures EEG responses to emotional video stimuli. A critical methodological decision in such studies is how to handle the "Baseline" (pre-stimulus) recording. The traditional *Reactivity Hypothesis* suggests that the baseline represents noise or a neutral state to be subtracted.

This study tests the competing *Fingerprint Hypothesis*: that the baseline contains a stable, high-value biometric signature. We compare the identifiability of subjects using standard reactivity features against a raw state concatenation approach.

2 Methods

2.1 Data Processing

Raw EEG (14 channels, 128 Hz) was band-pass filtered (1–50 Hz). Power Spectral Density (PSD) was computed for Theta (4–8 Hz), Alpha (8–13 Hz), and Beta (13–30 Hz) bands using Welch's method.

2.2 Feature Extraction Pipelines

Two parallel feature sets were generated to test the hypothesis:

1. **Reactivity (Δ):** Calculated as the arithmetic difference between the stimulus and baseline power.

$$X_{reactivity} = X_{stimulus} - X_{baseline}$$

2. **Concatenation (State):** Both vectors were preserved and appended.

$$X_{concat} = [X_{baseline}, X_{stimulus}]$$

2.3 Statistical Analysis

Subject identification was performed using a Random Forest Classifier (100 estimators, 5-fold Stratified CV). Feature stability was quantified using the Intraclass Correlation Coefficient (ICC).

3 Results

3.1 Subject Identification Accuracy

We compared the classification performance of both feature sets against the statistical chance level (4.35%). As shown in Table 1, the Concatenation method significantly outperformed the Reactivity method.

Table 1: Comparative Accuracy of Feature Extraction Methods

Method	**Accuracy**	**vs. Chance**	**Data Source**
Reactivity (Δ)	47.34%	10.8×	`ml_results_reactivity.csv`
Concatenation	**95.89%**	**22.1**×	`ml_comparison_concat.csv`

While Reactivity provided information above chance, it lost nearly half of the discriminatory power available in the raw signal.

3.2 Variance and Stability Analysis

To understand the mechanism of this performance gap, we analyzed the ICC of the Frontal Alpha Asymmetry (FAA) feature.

Table 2: Trait Stability (ICC) Analysis

Feature State	**ICC Value**	**Interpretation**
Δ FAA (Reactivity)	0.10	Low Stability (Noise Dominated)
Stimulus FAA (Raw)	**0.70**	**High Stability (Strong Trait)**

The raw stimulus signal showed a high degree of within-subject stability (ICC = 0.70). However, because the baseline signal is also highly stable and correlated with the stimulus, subtracting them (Stim − Base) canceled out the stable "Trait" component, leaving a residual signal with low stability (ICC = 0.10).

4 Discussion

4.1 The Cost of Subtraction

The results highlight a fundamental flaw in using simple subtraction for biometric tasks. The "Subject Fingerprint"—likely driven by anatomical factors such as skull thickness and cortical folding—is present in both the baseline and the stimulus. By subtracting them, the Reactivity method effectively removes the most distinct biometric features.

4.2 The Power of Concatenation

The Concatenation method (95.89% accuracy) succeeds because it provides the classifier with the full context. The model can learn non-linear relationships, such as "Subject A typically has high Baseline Alpha that suppresses slightly during Stimulus," rather than just seeing the suppression value alone.

5 Conclusion

Based on the analysis of the DREAMER dataset, we conclude that **raw spectral states are superior to reactivity metrics for subject identification.** The Reactivity method discards valuable trait information, reducing accuracy from $\approx$ 96% to $\approx$ 47%. Future research in EEG biometrics should prioritize state-preserving feature extraction methods.