Decoding Error-Related Potentials under Multisensory Feedback with Varying Congruency

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IEEE SMC 2026
Paper 1806

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Motivation and contribution

Observation-based ErrPs

Neural responses to perceived errors
Passive monitoring of another agent's actions

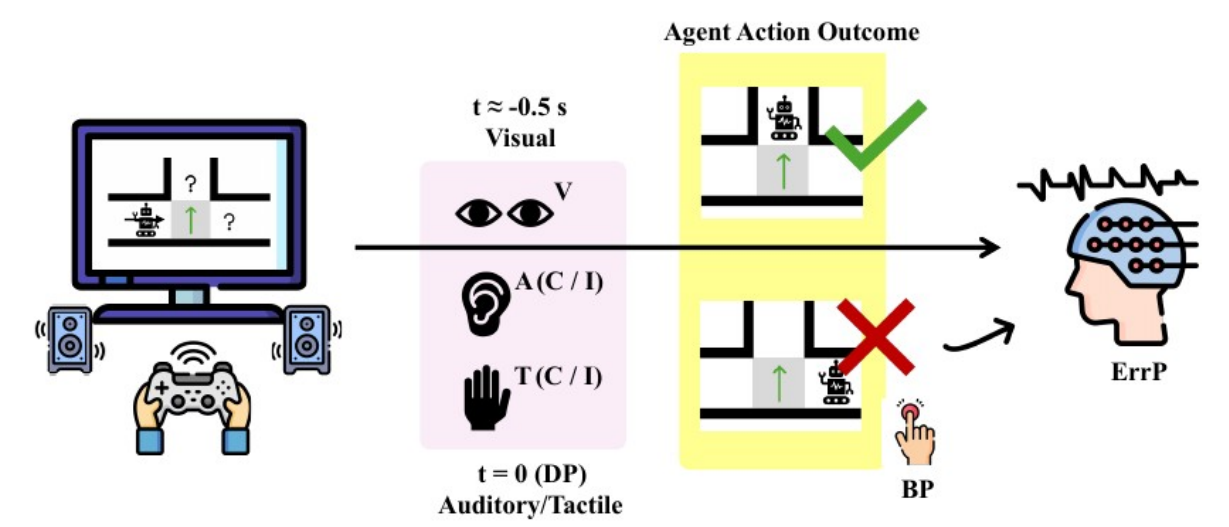
Challenge

Changing sensory conditions introduce temporal variability and context dependence

A learning framework for heterogeneous multisensory feedback

Data: segmentation-and-reconstruction (S&R) augmentation
Model: multi-branch EEGNet for parallel temporal features
Training: pooled conditions with auditory/tactile supervision

Experimental paradigm



12 participants
720 trials per participant

Visual arrow: ≈ 0.5 s before DP
Auditory/tactile feedback: at DP
Button press: perceived error

DP = decision point BP = button press

Binary target: perceived-error vs. non-error trials

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Feedback conditions and congruency

Condition	Auditory	Tactile
V	Absent	Absent
VA-c / VA-i	C / I	Absent
VT-c / VT-i	Absent	C / I
VAT-c	C	C
VAT-A-i	I	C
VAT-T-i	C	I
VAT-AT-i	I	I

V: 144 trials Each other condition: 72 trials

Congruent (C)

Cue-consistent action:
positive tone / weak vibration
Cue-inconsistent action:
negative tone / strong vibration

Incongruent (I)

The corresponding auditory or tactile mapping is reversed

EEG acquisition and preprocessing

Recording and cleaning

64 channels, 1,000 Hz
Common-average reference
1–30 Hz band-pass filter
ICA artifact removal

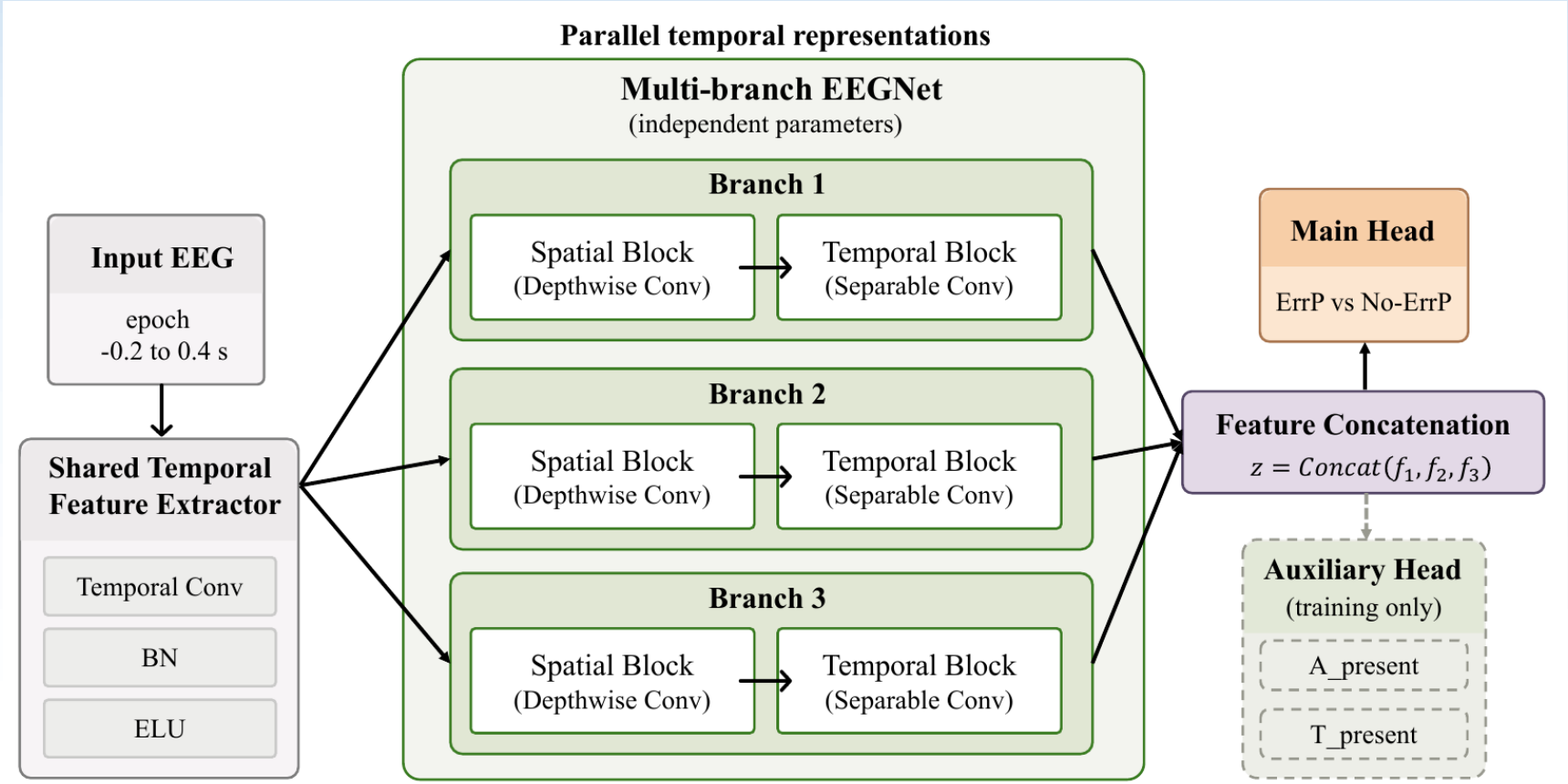
Analysis input

FCz only
Epoch: −0.2 to 0.4 s
Baseline: −0.2 to 0 s
Residual artifact rejection
Trial-wise z-score normalization

Event anchors differ by trial type

Perceived error: button press (BP)
Non-error: decision point (DP)

Multi-branch EEGNet



Independent branches, without fixed modality assignments

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Augmentation and pooled training

S&R augmentation

Split each epoch into temporal segments
Recombine segments within the same error class
With Aux: also match auditory/tactile presence

Training folds only. Held-out test folds receive no augmentation.

Pooled training and evaluation

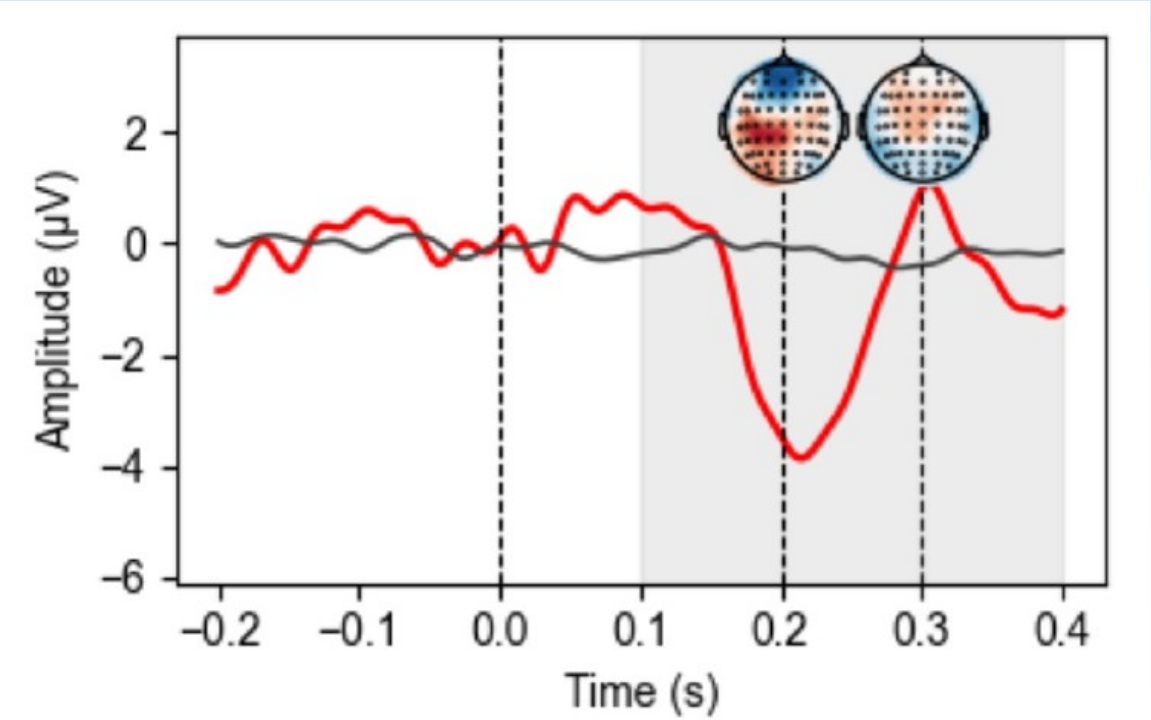
Combine all conditions within each subject
Trial-wise stratified five-fold cross-validation
Class-weighted cross-entropy; Adam optimizer

Training objective

$L = L_{main} + \lambda (L_A + L_T)$

A / T = modality presence
Auxiliary heads: training only

Grand-average ErrP responses at FCz



Perceived-error trials (red)

N200: negative deflection ≈ 200 ms
P300: positive peak ≈ 300 ms
Mainly frontocentral difference

Non-error trials (gray)

No comparable structured response

Different event anchors and button presses leave a possible motor contribution

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Model comparison across nine conditions

Accuracy (%), mean ± SD across 12 subjects

Condition	EEGNet	EEGNet + S&R	Multi-branch + S&R	Pooled multi-branch + S&R + Aux
V	79.23 ± 5.81	80.68 ± 5.53	80.85 ± 6.06	**81.71 ± 5.90**
VA-c	84.40 ± 7.61	85.06 ± 7.70	86.64 ± 4.16	**88.08 ± 6.38**
VA-i	77.39 ± 6.56	79.29 ± 6.97	82.24 ± 5.67	**82.06 ± 4.79**
VT-c	87.98 ± 4.29	88.90 ± 3.67	90.02 ± 4.25	**89.93 ± 3.77**
VT-i	83.09 ± 8.50	83.80 ± 8.04	86.12 ± 7.11	**86.34 ± 5.89**
VAT-c	85.77 ± 5.44	87.50 ± 5.42	88.53 ± 4.09	**91.20 ± 4.86**
VAT-A-i	82.18 ± 5.46	84.50 ± 4.85	84.47 ± 5.39	**87.50 ± 3.80**
VAT-T-i	83.95 ± 4.83	85.12 ± 5.27	87.29 ± 3.92	**89.58 ± 5.54**
VAT-AT-i	80.53 ± 8.63	83.48 ± 5.99	84.43 ± 5.34	**86.46 ± 4.32**

Largest pooled gains in VAT; VA-i and VT-c do not improve over Multi-branch + S&R

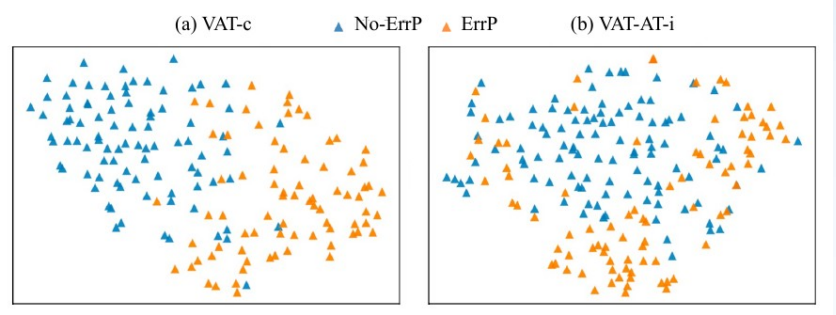
Congruency under pooled training

Table II: paired congruency comparisons

Comparison	Mean ΔAcc.	p	q
VA-c vs. VA-i	+0.060	0.032	0.040
VT-c vs. VT-i	+0.036	0.027	0.040
VAT-c vs. VAT-A-i	+0.037	0.021	0.040
VAT-c vs. VAT-T-i	+0.016	0.229	n.s.
VAT-c vs. VAT-AT-i	+0.048	0.003	0.017

Two-sided Wilcoxon signed-rank tests
Benjamini–Hochberg FDR correction
ΔAcc. uses fraction units; n.s. means $q \geq 0.05$

Fig. 4: learned feature representations



VAT-c: clearer overall separation
VAT-AT-i: more overlap
Qualitative evidence only

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Discussion and conclusion

Conclusion

Complementary data, model, and training strategies
support decoding across heterogeneous conditions
Condition-dependent gains, especially under VAT

Limitations and next steps

Different event anchors and motor activity: use matched anchors or motor controls
FCz-only input: extend to multichannel EEG
Subjective error labels: assess transfer to tasks with objective error labels

Thank you

Questions and discussion

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