Escuela Politécnica Superior

UAM Universidad Autónoma de Madrid

IEEE SMC 2026
Bellevue, WA USA

CHARACTERIZING THE SPEED–ACCURACY TRADE-OFF IN P300-BASED BRAIN–COMPUTER INTERFACES

Javier Jiménez Rodríguez
Francisco de Borja Rodríguez Ortiz
Grupo de Neurocomputación Biológica
javier.jimenez01@uam.es

CC BY SA

MOTIVATION

If you could make a P300-based BCI **faster**, but only **at the cost of making it less accurate**, how much accuracy would you be willing to give up?

INDEX OF CONTENTS

1 Introduction
- What is a BCI?
- P300-ERP potential
- Speed–Accuracy Trade-off
- Scaling laws

2 Data employed
- Rapid Serial Visual Presentation
- Row–Column Paradigm

3 Methodology
- Speed–Accuracy contributions
- Optimization procedure
- Gain–Conservation Trade-off Curves

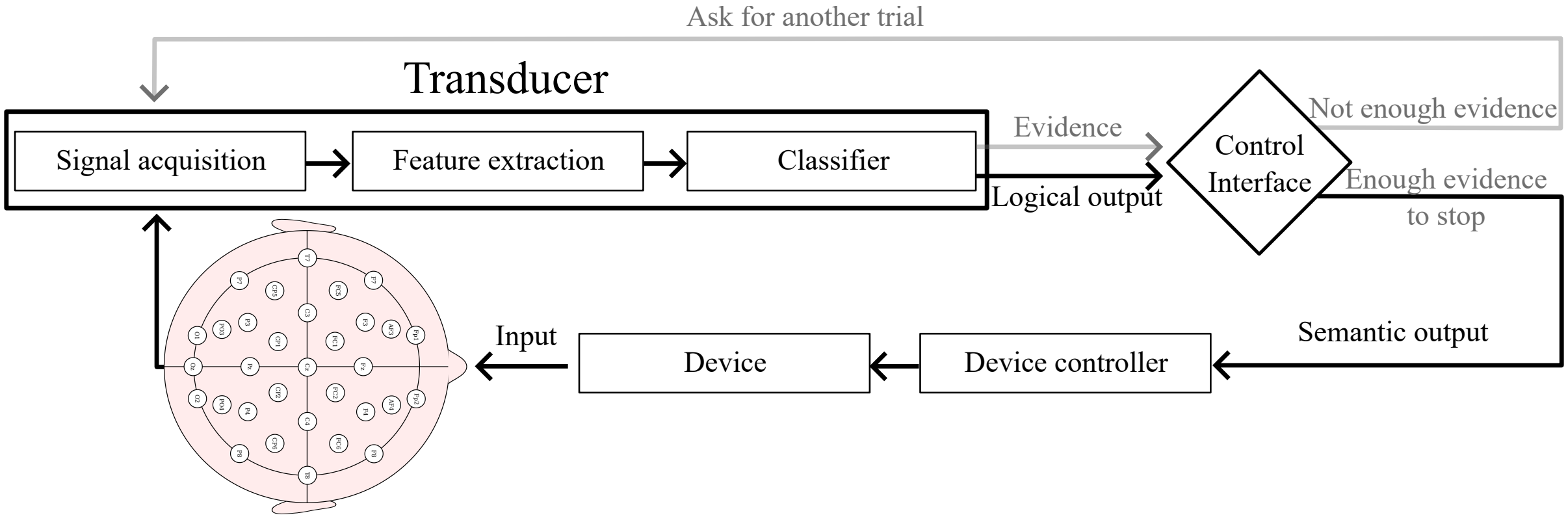
4 Results
- Population-Level Gain–Cons Trade-off Curves
- Gain–Cons Trade-off Curves Differences
- Evidence Scaling Exponent Distributions

5 Conclusions
- Limitations
- Conclusions

6 Questions

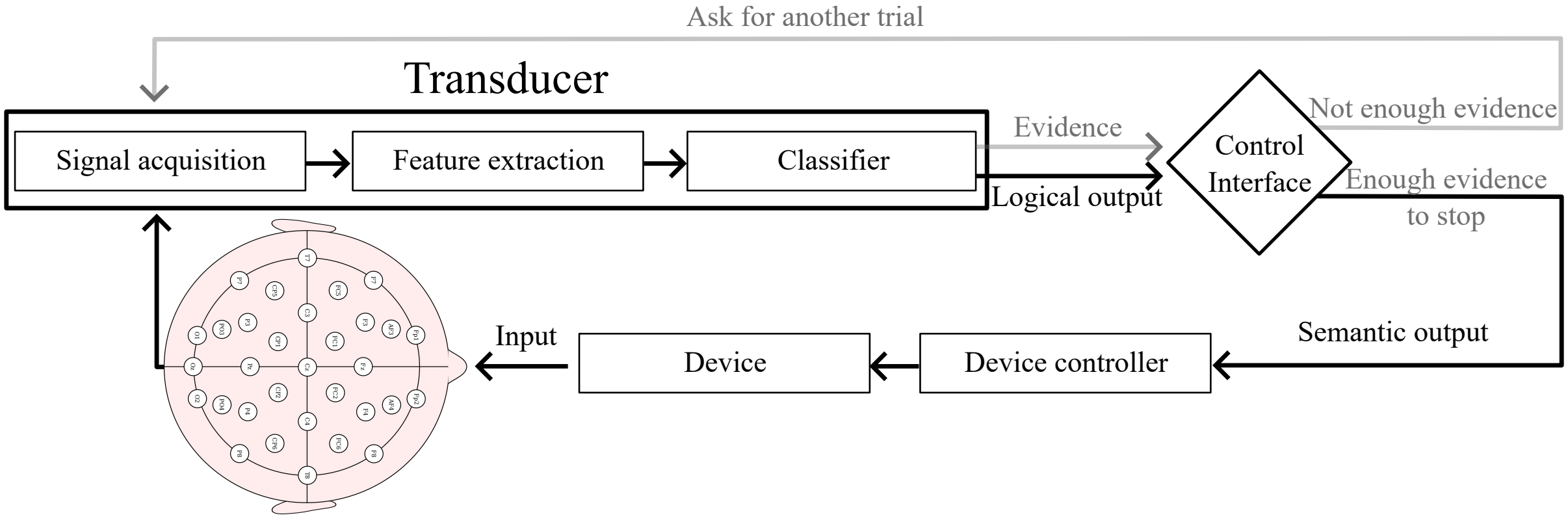
INTRODUCTION

WHAT IS A BRAIN–COMPUTER INTERFACE?



Adapted from Jiménez, J. and Rodríguez, F.B. (2026a): https://arxiv.org/abs/2606.00106

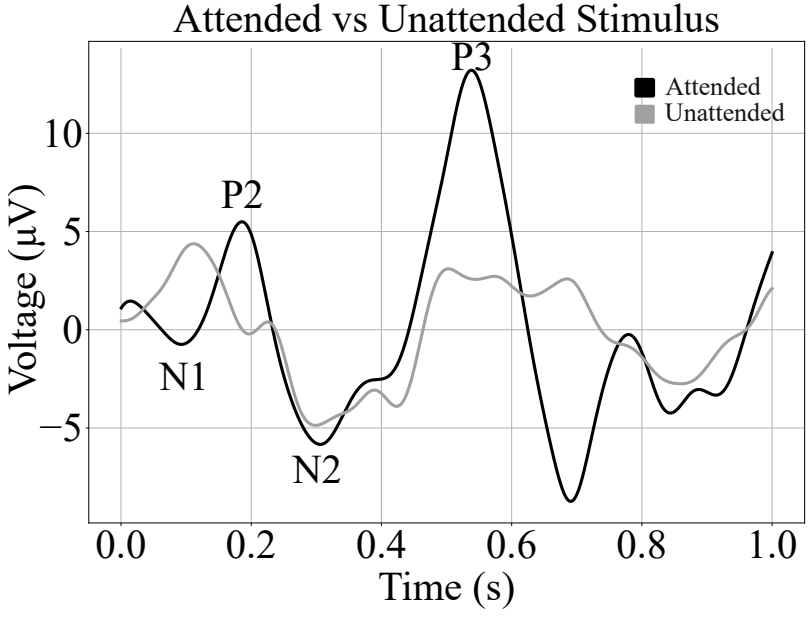
WHAT IS A BRAIN–COMPUTER INTERFACE?

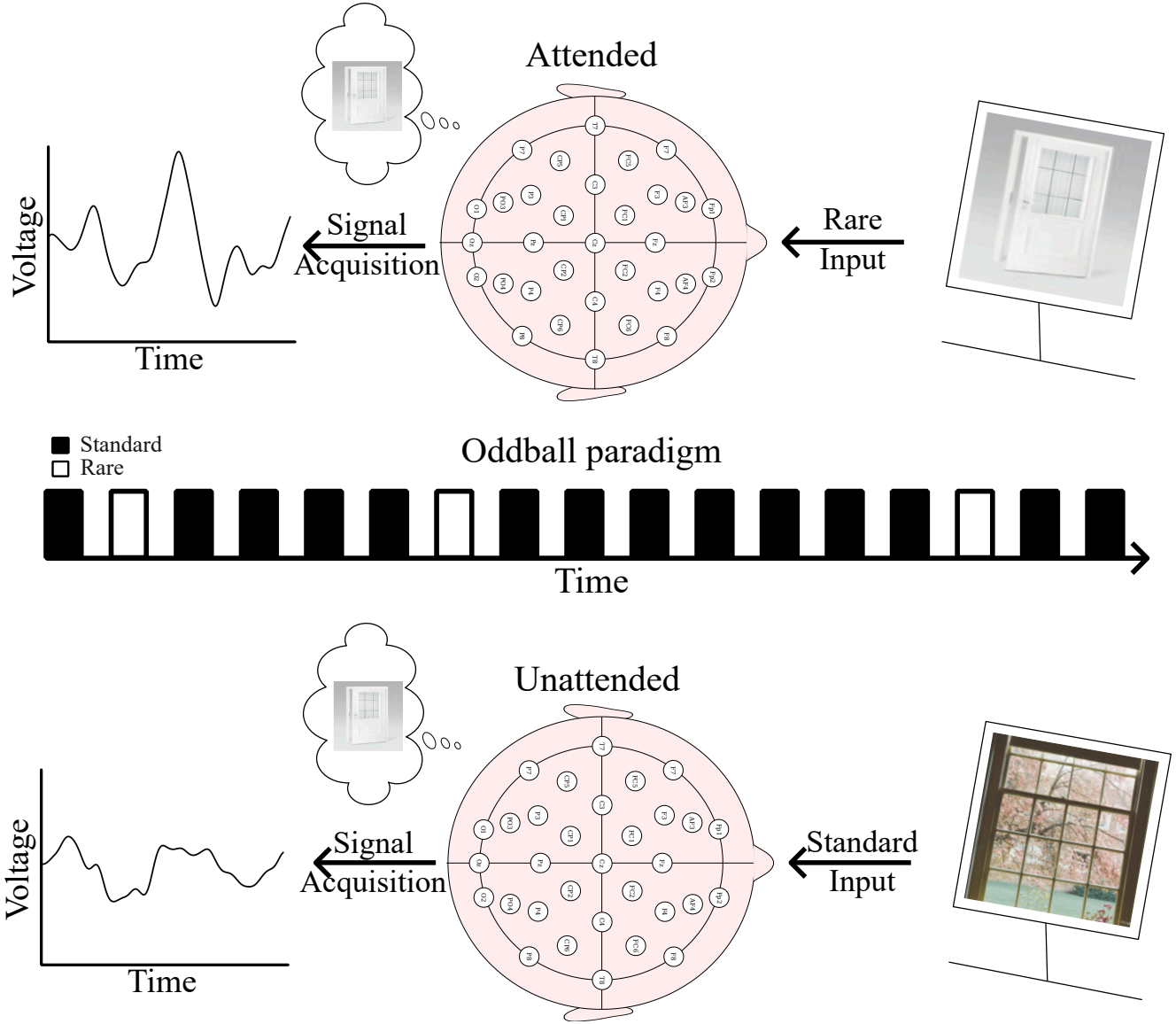


🖼️For example, a SIMULATION of sequential series of images🖥️

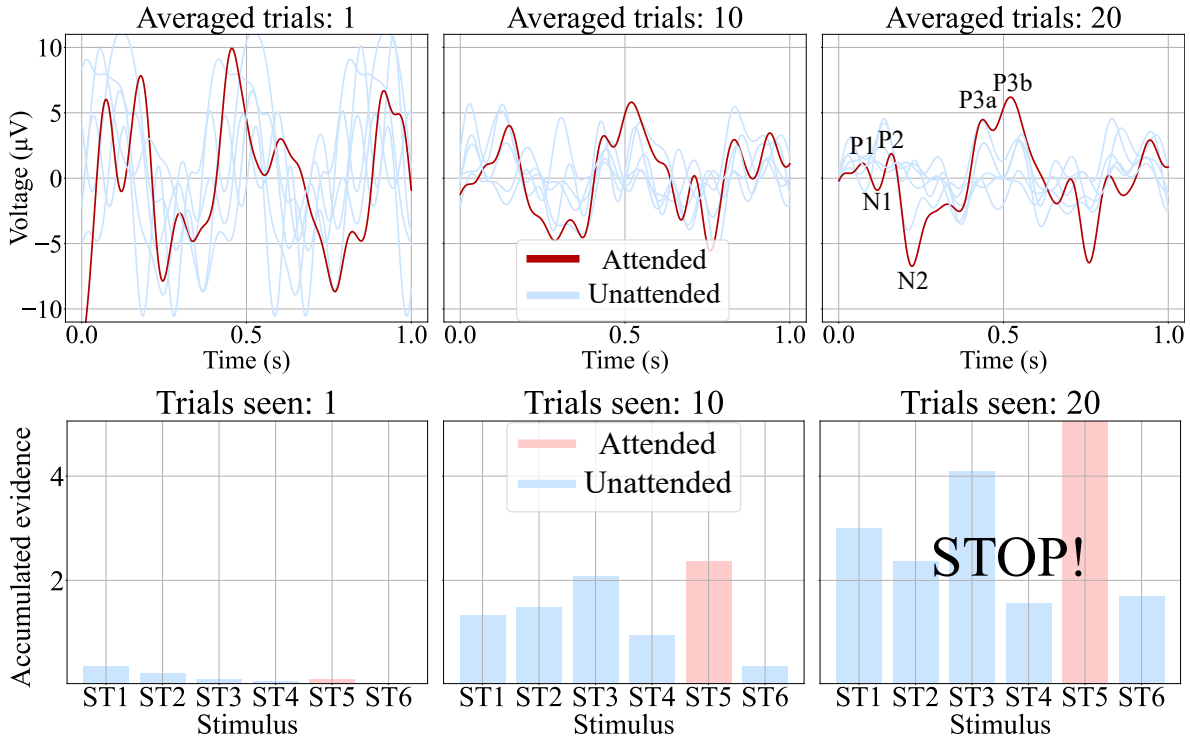
Adapted from Jiménez, J. and Rodríguez, F.B. (2026a): https://arxiv.org/abs/2606.00106

P300 EVENT-RELATED POTENTIAL





SPEED–ACCURACY TRADE-OFF

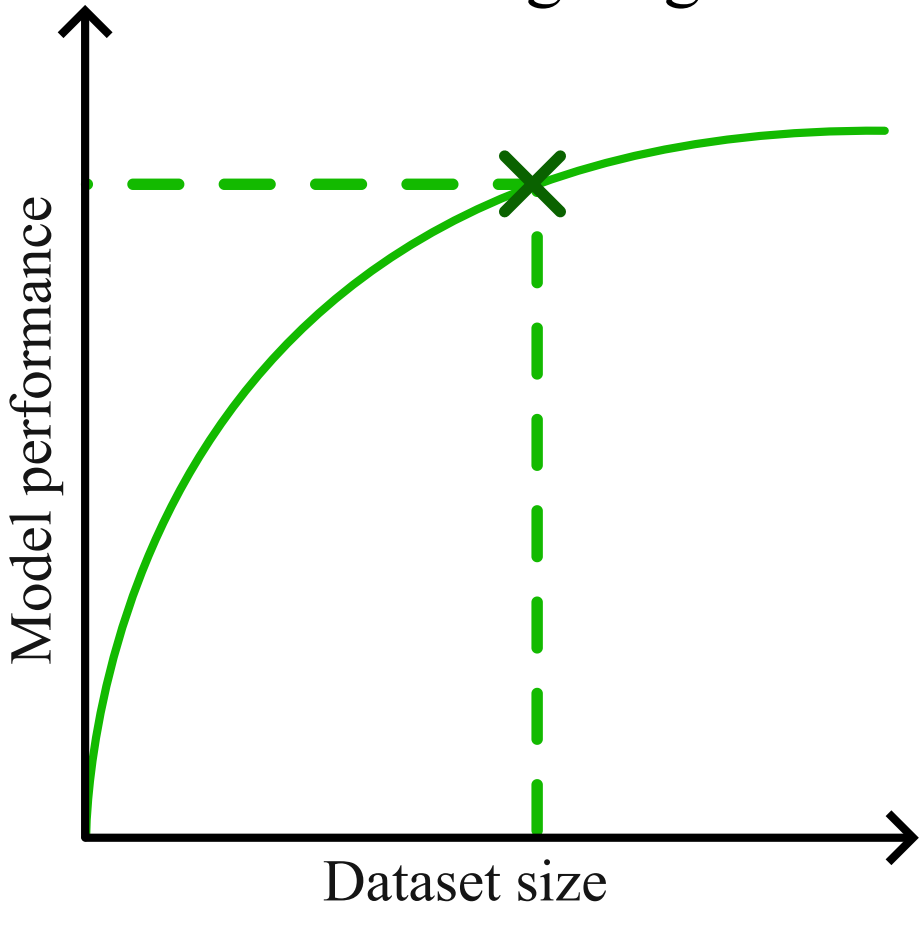


The more accurate a BCI is (↑ accuracy),
the slower it becomes (↓ speed)—and vice versa.

Adapted from Jiménez, J. and Rodríguez, F.B. (2026b): https://doi.org/10.1007/978-981-95-9578-5_12

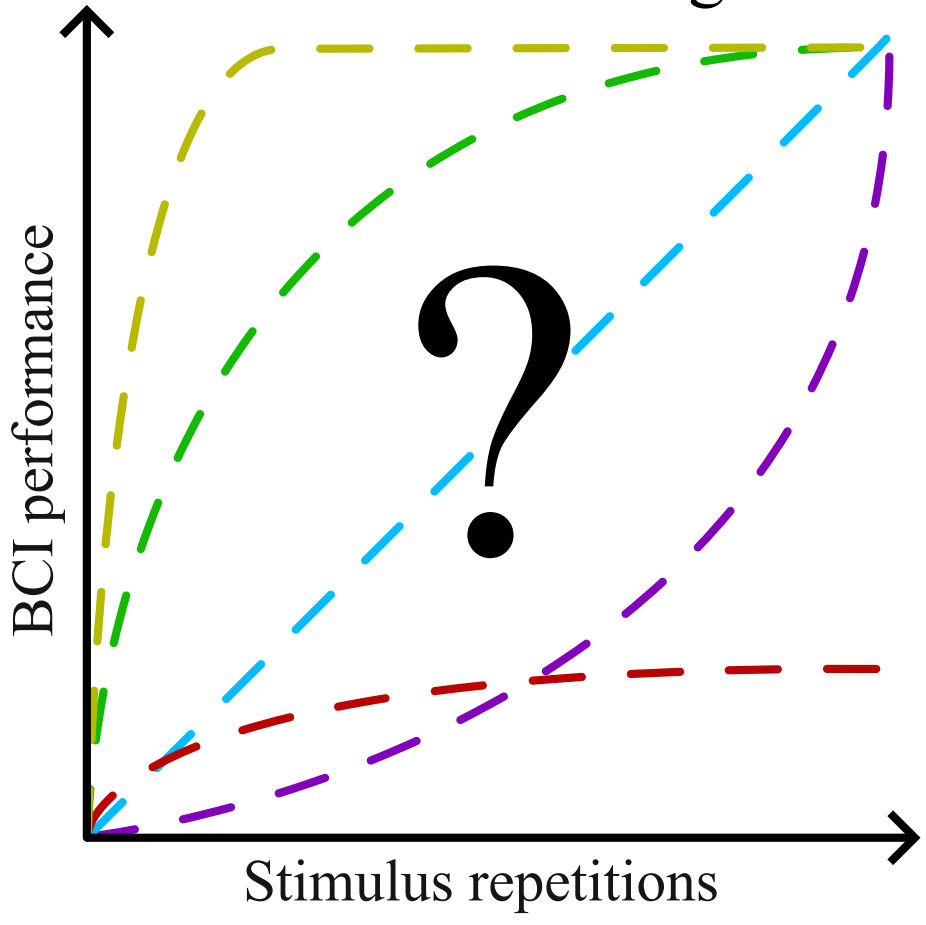
SCALING LAWS

Training stage



How much do I have to increase my dataset size to achieve better performance?

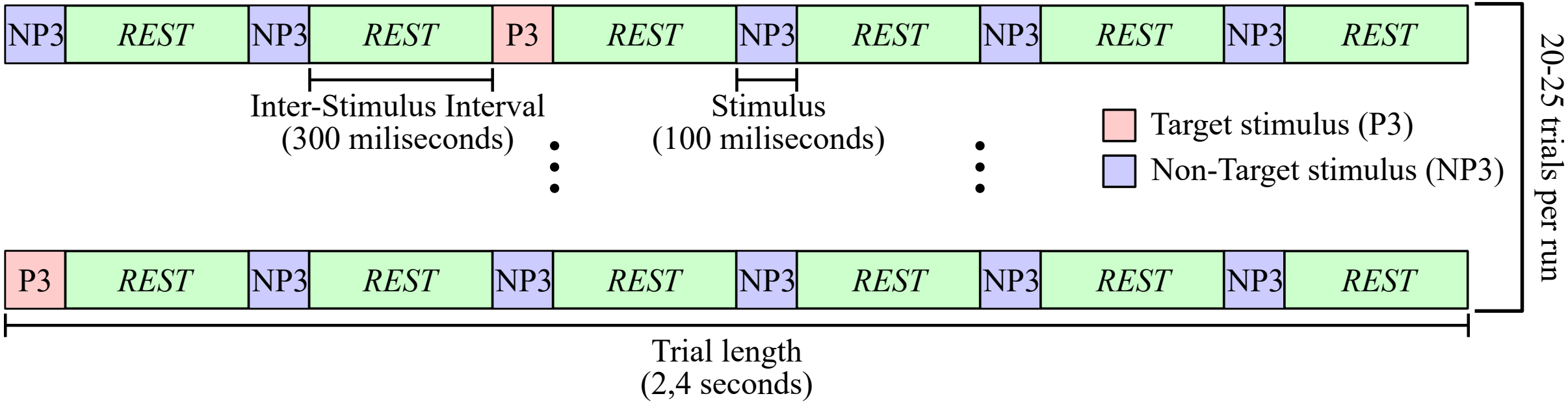
Inference stage



How many trials do I need to achieve better performance?

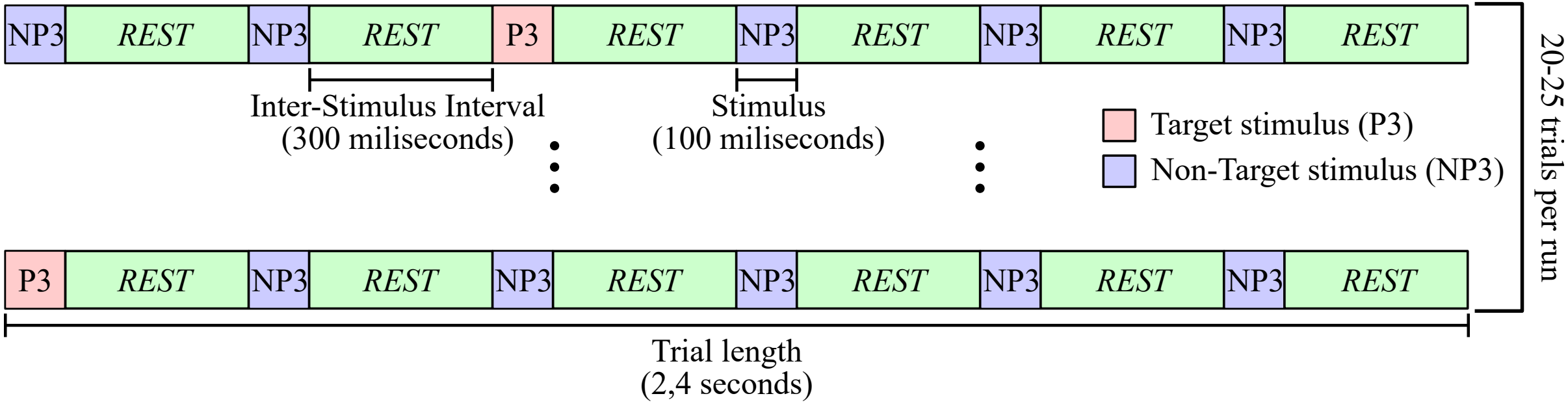
DATA EMPLOYED

RAPID SERIAL VISUAL PRESENTATION (RSVP)



Each trial contains **six stimuli with a single target**. It includes recordings from 8 participants acquired with 32 EEG electrodes arranged according to the 10–20 system. (Hoffmann et al. 2008)

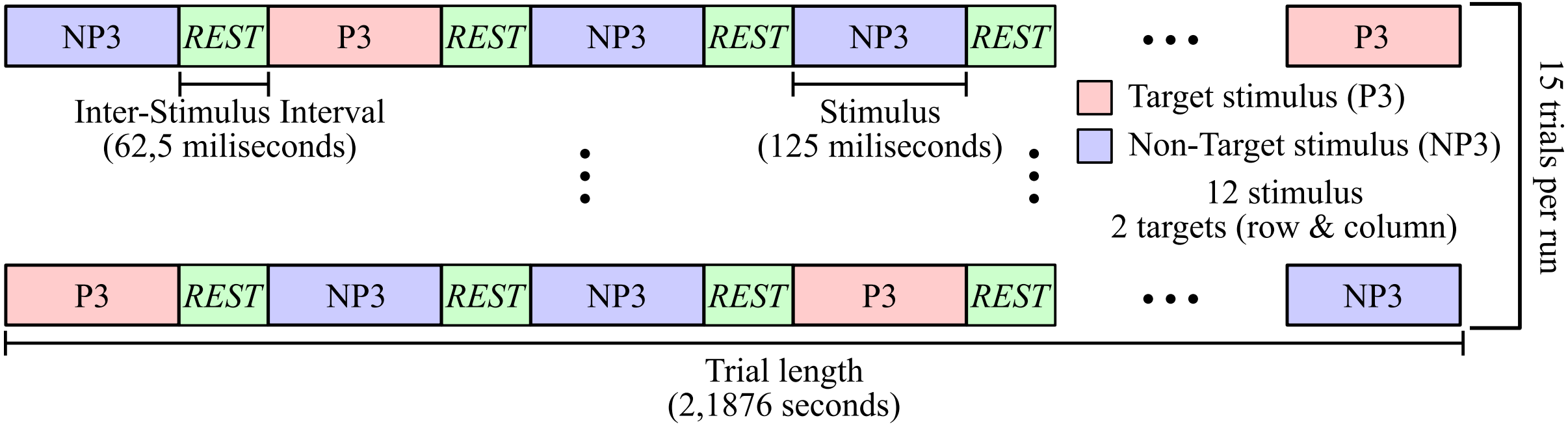
RAPID SERIAL VISUAL PRESENTATION (RSVP)



Each trial contains **six stimuli with a single target**. It includes recordings from 8 participants acquired with 32 EEG electrodes arranged according to the 10–20 system. (Hoffmann et al. 2008)

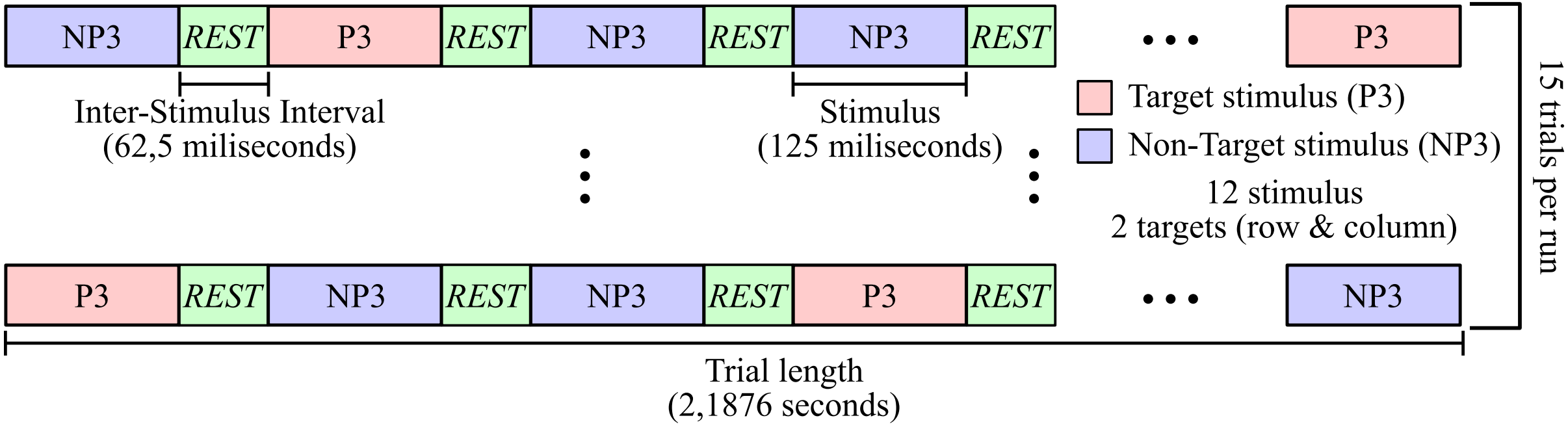
🖼️ RSVP experiment 💻

ROW–COLUMN PARADIGM (RCP)



Each trial presents **twelve stimuli** corresponding to row and column flashes. **Two stimuli per trial represent the target row and column**, and the dataset includes 55 participants recorded with EEG. We also employed a **theoretical relaxation of RCP**. (Won et al. 2022)

ROW–COLUMN PARADIGM (RCP)



Each trial presents **twelve stimuli** corresponding to row and column flashes. **Two stimuli per trial represent the target row and column**, and the dataset includes 55 participants recorded with EEG. We also employed a **theoretical relaxation of RCP**. (Won et al. 2022)

METHODOLOGY

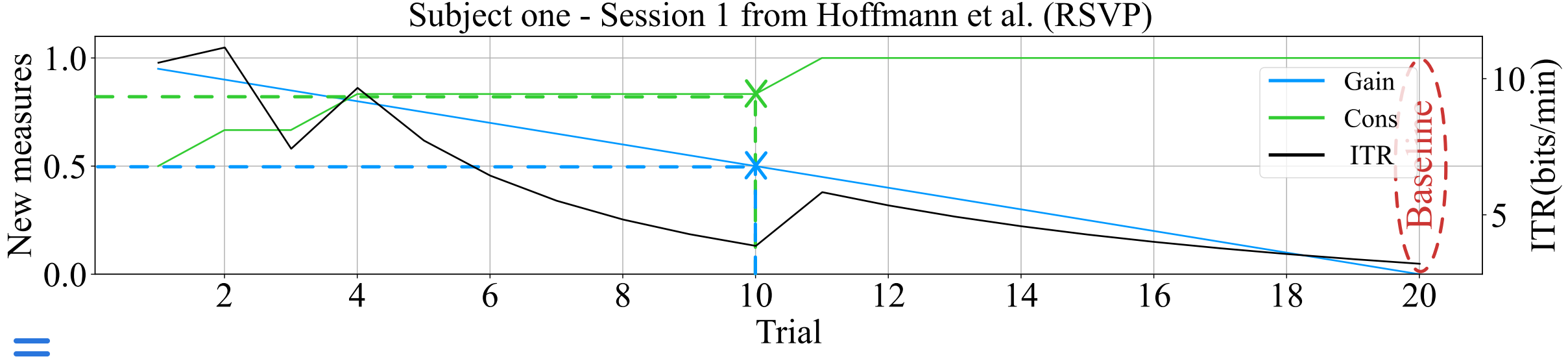
GAIN–CONSERVATION MEASUREMENTS

Speed-*Gain* measures the relative proportion of trials saved (t^*) with respect to a baseline number of trials (t).

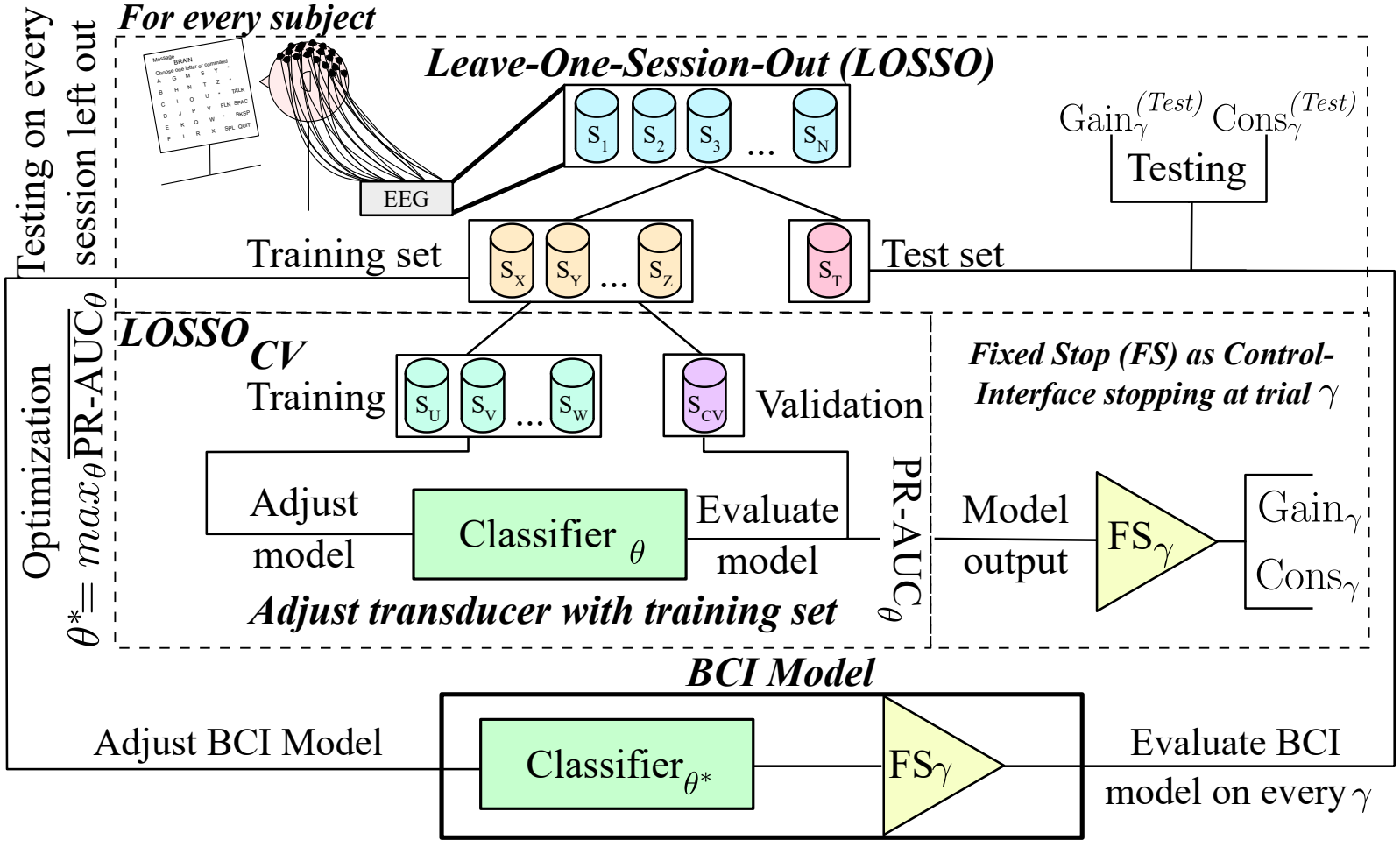
$$Gain(t, t^*) = \frac{t - t^*}{t}$$

Accuracy-*Conservation* measures the relative proportion of accuracy preserved ($A(i^*)$) with respect to a baseline accuracy ($A(i)$).

$$Cons(i, i^*) = 1 - \frac{A(i) - A(i^*)}{A(i)}$$

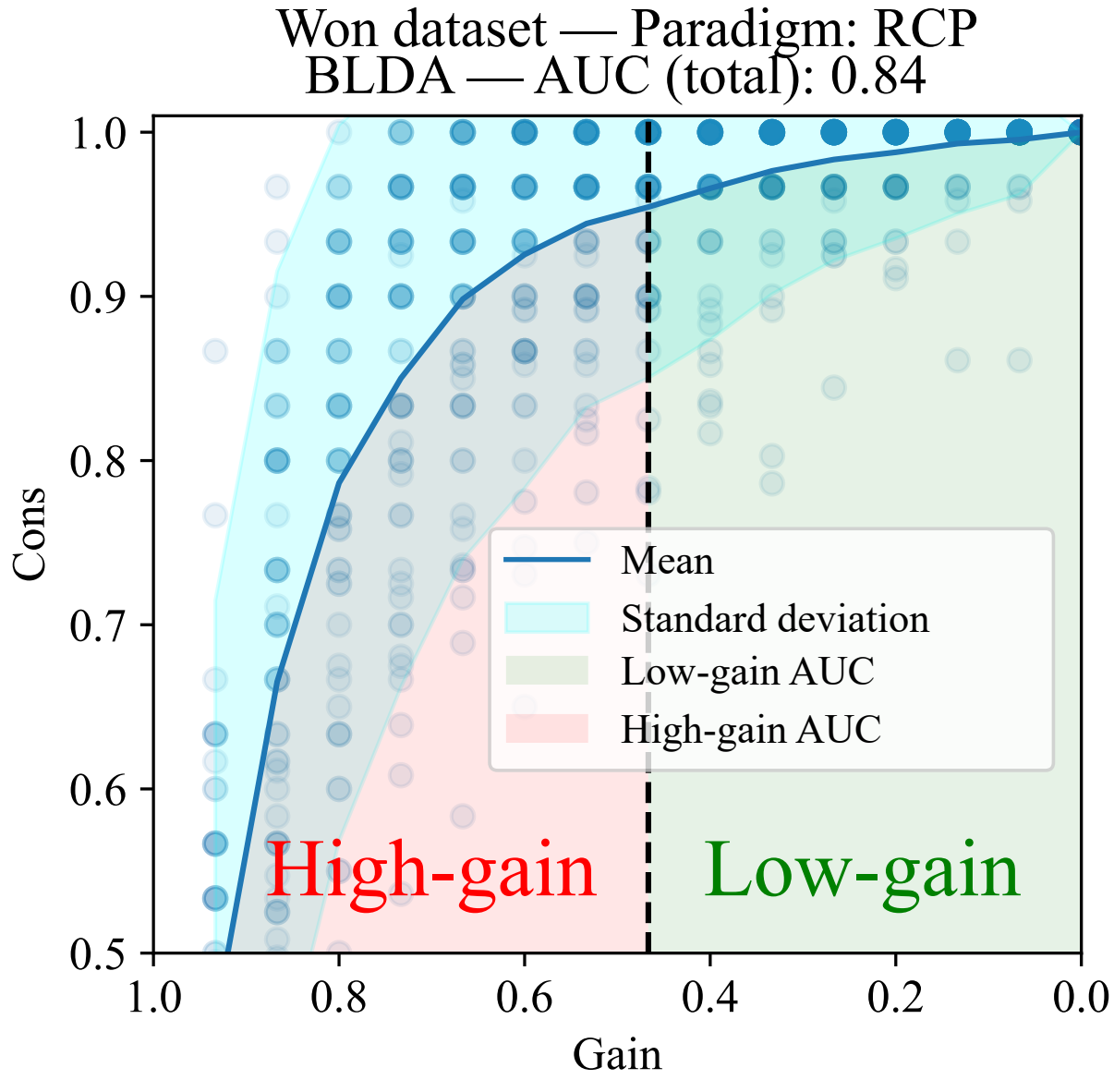


OPTIMIZATION PROCEDURE



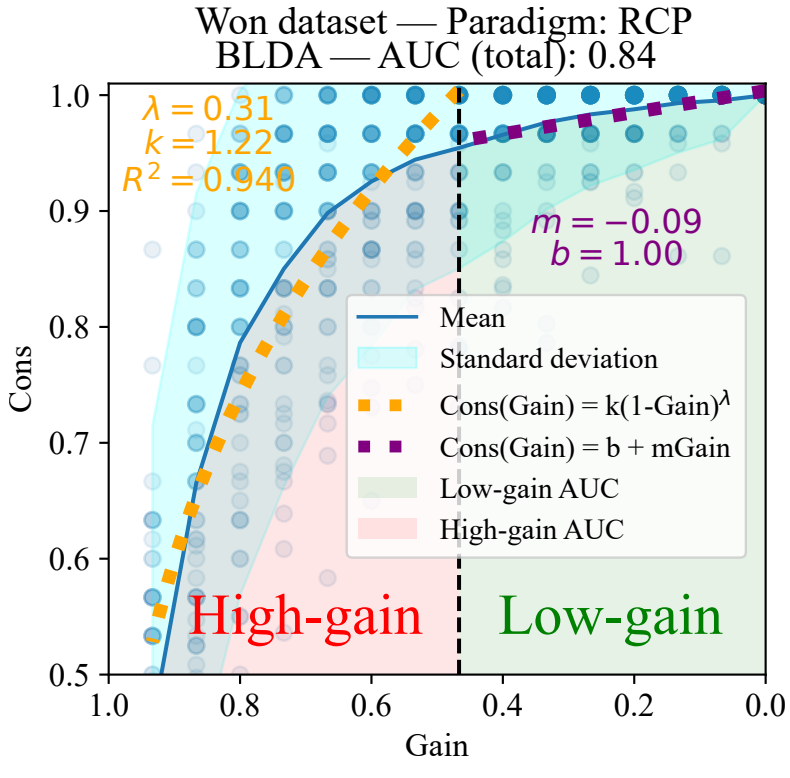
Adapted from Jiménez, J. and Rodríguez, F.B. (2026a): https://arxiv.org/abs/2606.00106

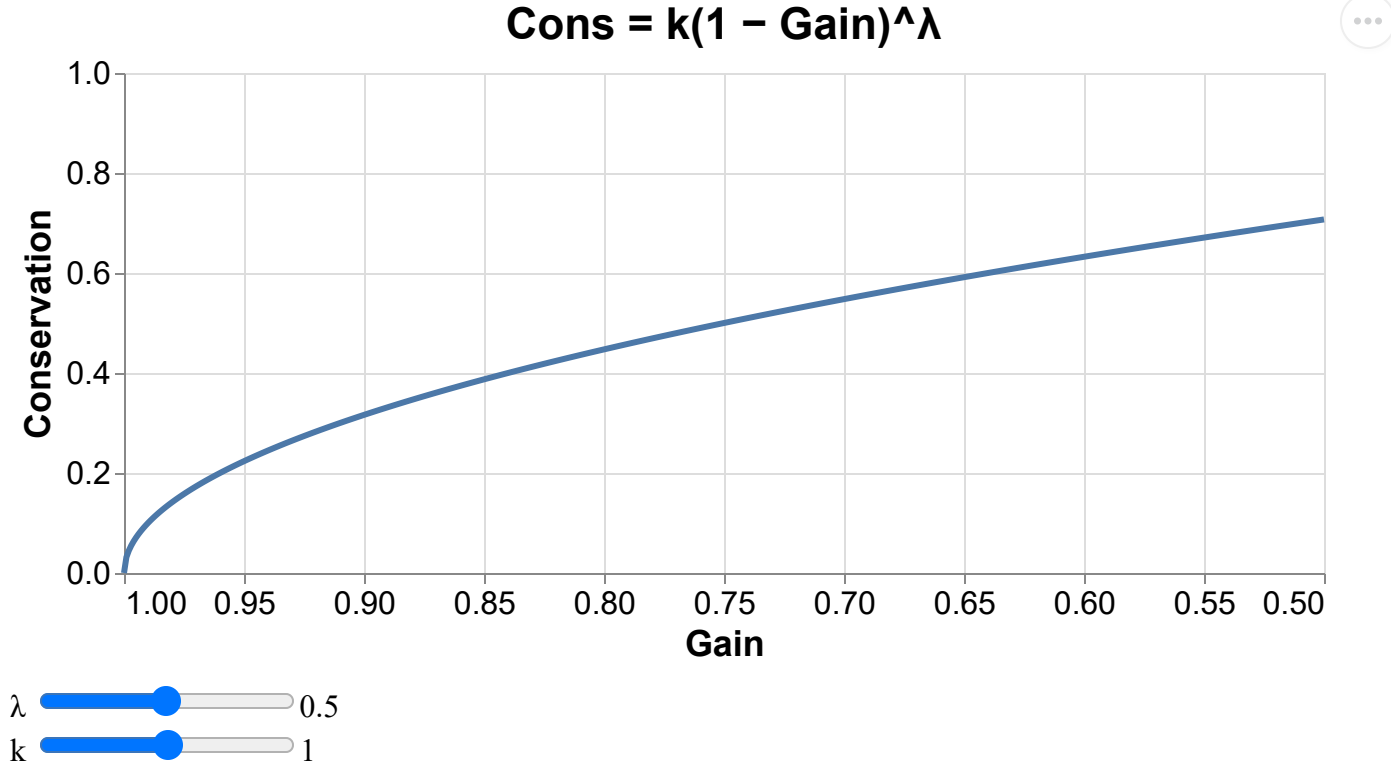
GAIN–CONSERVATION TRADE-OFF CURVES



GAIN–CONSERVATION TRADE-OFF CURVES

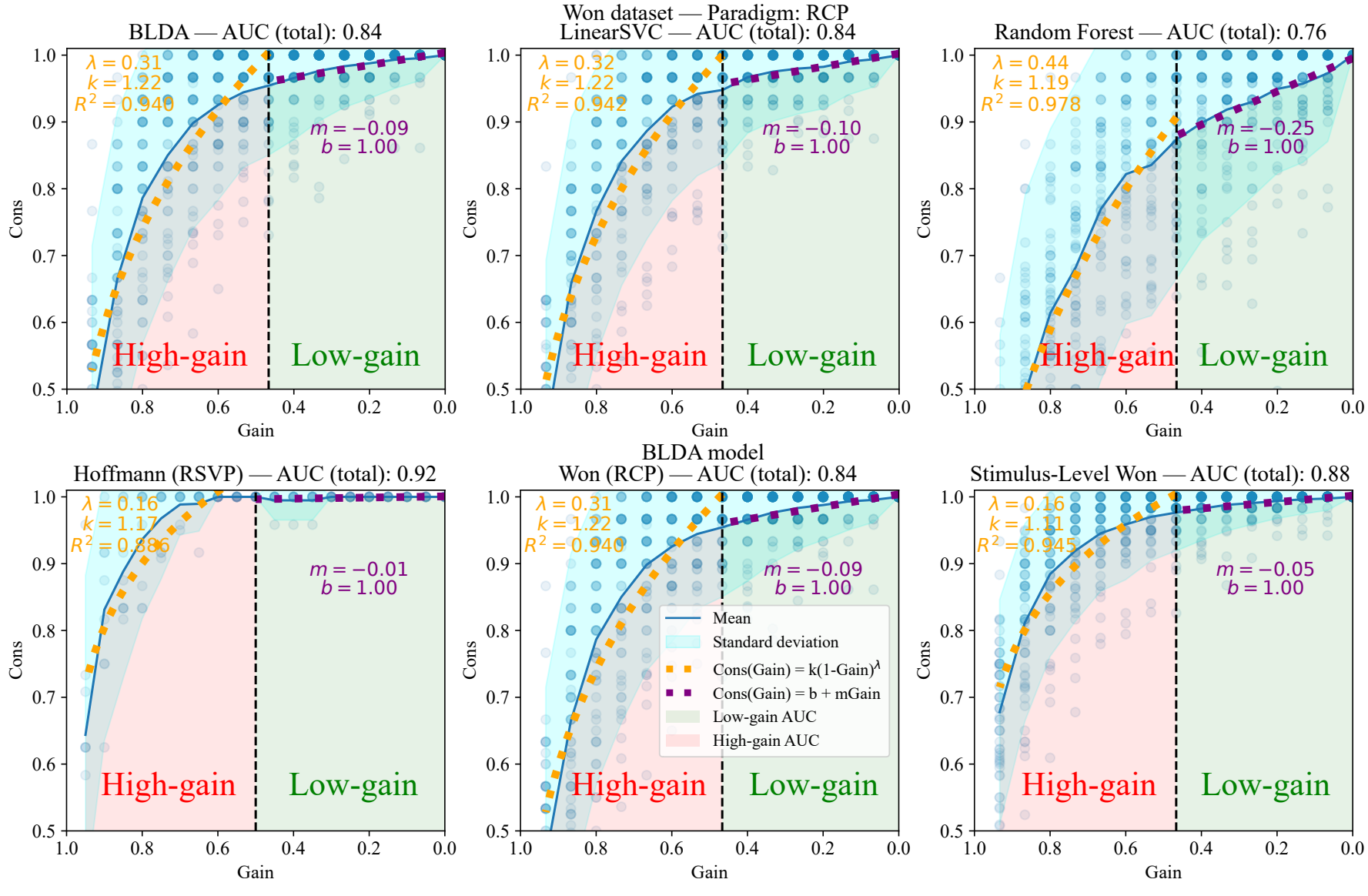
$$\text{Conservation}(\text{Gain}) = \begin{cases} k(1-\text{Gain})^{\lambda} & \text{Gain} \geq 0.5 \\ b + m \times \text{Gain} & \text{Gain} < 0.5 \end{cases},$$



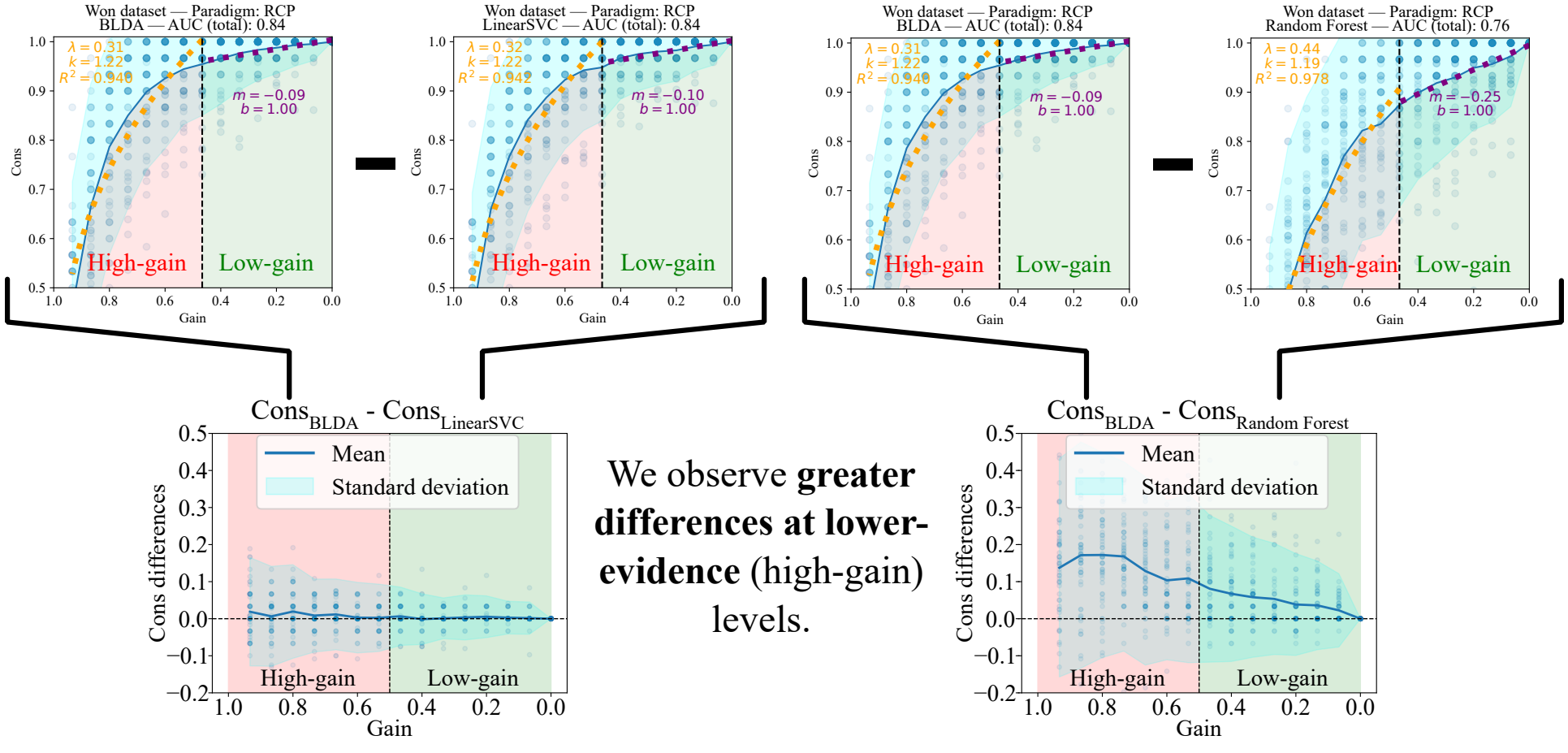


RESULTS

POPULATION-LEVEL GAIN–CONS TRADE-OFF CURVES



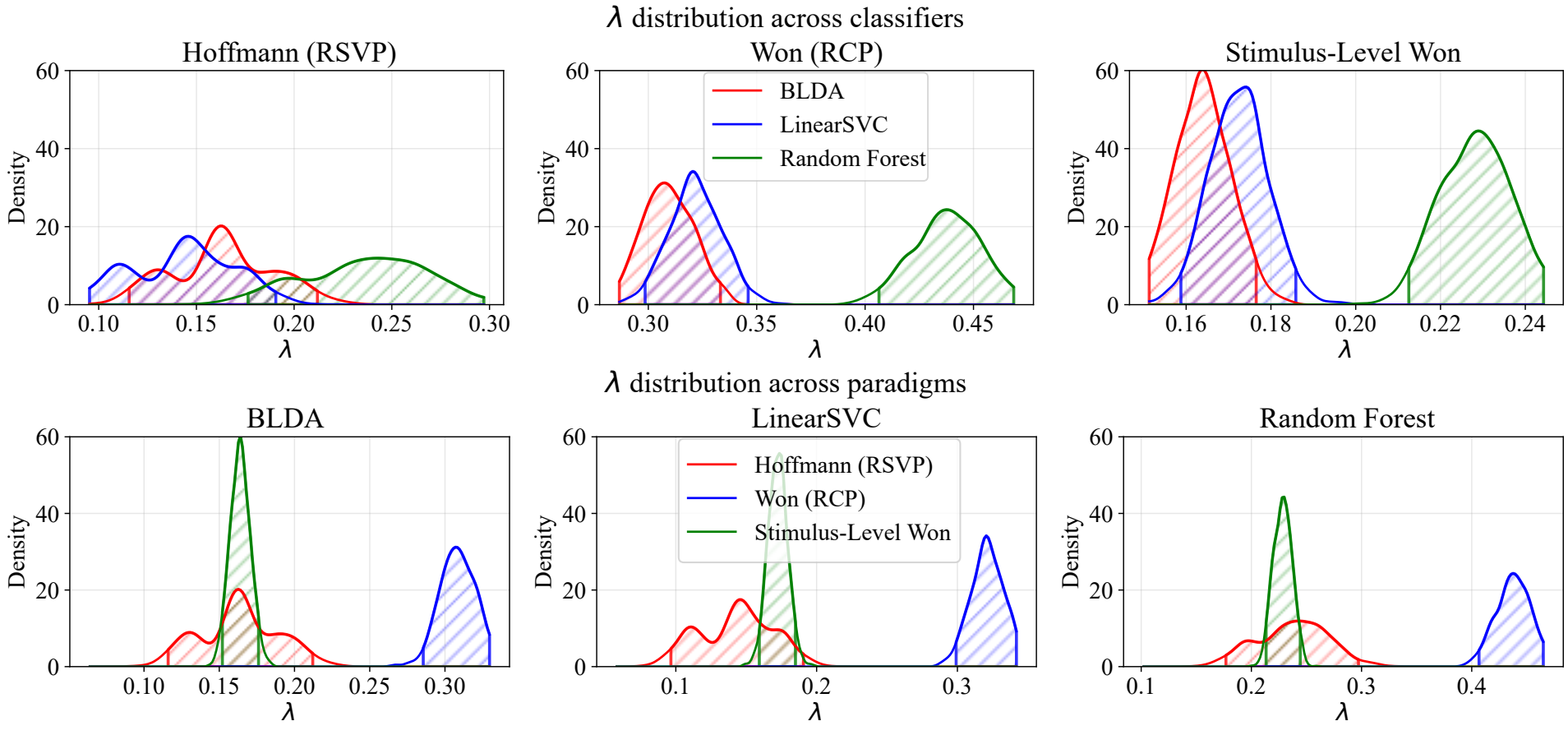
GAIN–CONS TRADE-OFF CURVES DIFFERENCES



We observe **greater differences at lower-evidence** (high-gain) levels.

This information is lost when either using aggregated metrics or measuring performance at a fixed trial—as **performance evolution is not tracked**.

EVIDENCE SCALING EXPONENT DISTRIBUTION



λ reflects how effectively classifiers and paradigms extract discriminative information. It also serves as a **diagnostic tool** to debug/compare models' performance.

LIMITATIONS AND CONCLUSIONS

LIMITATIONS

LIMITATIONS

- We only work with synchronous P300-based BCIs.

LIMITATIONS

- We only work with synchronous P300-based BCIs.
- Differences in trial structure and number may affect the timing of the saturation regime across paradigms.

LIMITATIONS

- We only work with synchronous P300-based BCIs.
- Differences in trial structure and number may affect the timing of the saturation regime across paradigms.
- Stimulus-Level RCP is a theoretical relaxation of Won et al. 2022 rather than an independent dataset.

CONCLUSIONS

CONCLUSIONS

1. Gain–Conservation Trade-off Curves summarize how accuracy evolves with available trials.

CONCLUSIONS

1. Gain–Conservation Trade-off Curves summarize how accuracy evolves with available trials.
2. This new perspective reveals regime-dependent performance differences obscured by aggregated metrics.

CONCLUSIONS

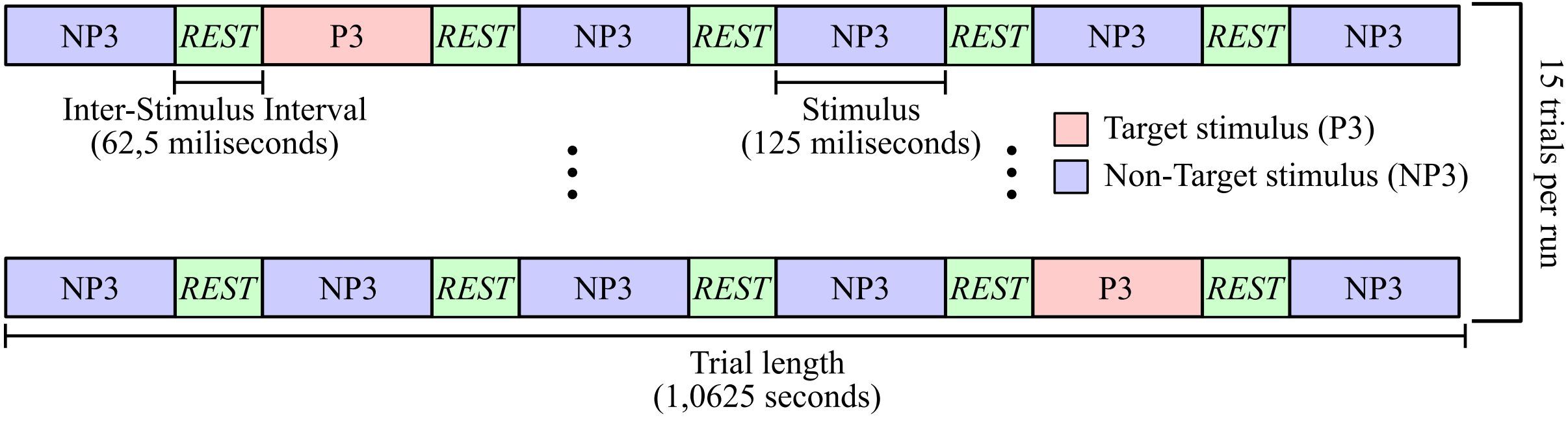
1. Gain–Conservation Trade-off Curves summarize how accuracy evolves with available trials.
2. This new perspective reveals regime-dependent performance differences obscured by aggregated metrics.
3. The evidence scaling exponent (λ) reflects evidence integration efficiency under low-evidence conditions.

QUESTIONS AND BIBLIOGRAPHY

- *Ulrich Hoffmann et al. "An Efficient P300-based Brain–Computer Interface for Disabled Subjects". In: Journal of Neuroscience Methods 167.1 (2008), pp. 115–125.*
- *Kyungho Won et al. "EEG Dataset for RSVP and P300 Speller Brain-Computer Interfaces". In: Scientific Data 9.1 (2022), p. 388.*
- ***Javier Jiménez and Francisco B. Rodríguez**. A Methodological Framework for Explicit Control of the Speed-Accuracy Trade-off in Brain-Computer Interfaces. (2026a). arXiv: 2606.00106.*
- ***Javier Jiménez and Francisco B. Rodríguez**. "A Novel Framework for Analyzing the Speed-Accuracy Trade-Off in Online P300-Based Brain-Computer Interfaces". In: Brain Informatics. Ed. by Angela Lombardi et al. Vol. 16348. Lecture Notes in Computer Science. Springer Nature, (2026b), pp. 150–161.*

Write me an email at javier.jimenez01@uam.es!

STIMULUS-LEVEL RCP



This formulation removes the conjunctive decoding constraint required for character identification by which both row and column have to be correctly decoded to obtain a character. Thus, enabling isolation of the structural contribution of the paradigm to the speed–accuracy trade-off.

SUBJECT-LEVEL BOOTSTRAPPING

