Learning to See Meaning in Visual Words and Objects

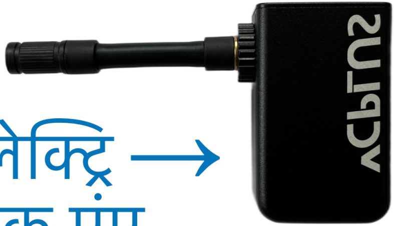
Alexander Enge

Humboldt-Universität zu Berlin

07.10.2025

Introduction

Introduction



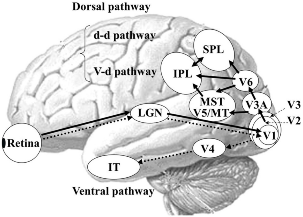
इलेक्ट्रि →
बाइक पंप

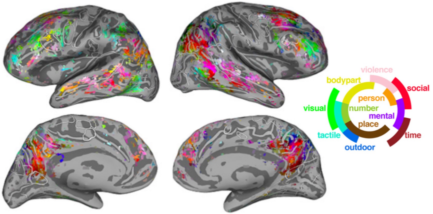
Introduction

Electric bike pump

Introduction

- Feed-forward visual system for core object recognition
- Semantic system based on object categories, linguistic contrasts, distributional statistics
- **Needs bi-directional interfaces**





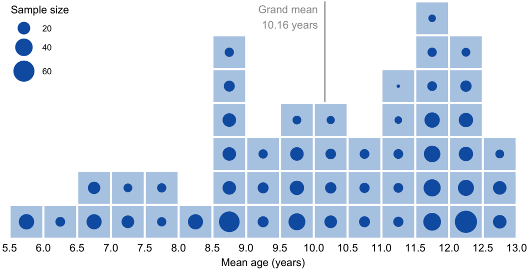
Binder et al. (2009); Deniz et al. (2019); DiCarlo et al. (2012); Felleman & Van Essen (1991); Huth et al. (2016)

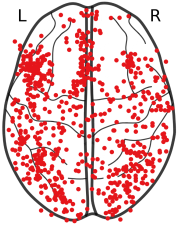
Introduction

- **Study 1: The semantic system in children**
  → Meta-analysis of the developing semantic system
- **Study 2: Visual semantics in learning to read**
  → Longitudinal fMRI study of reading acquisition
- **Study 3: Visual semantics in novel objects**
  → EEG training study on insight into object function

Study 1: The semantic system in children

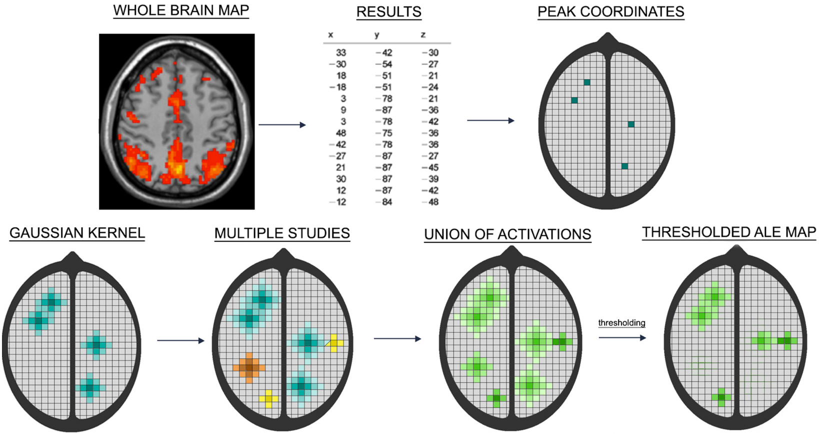
- 50 fMRI experiments on semantic cognition in children
- $N = 1018$ participants, mean age 5.5–12.8 years
- 687 peak coordinates (400, left 287 right)





Enge et al. (2021)

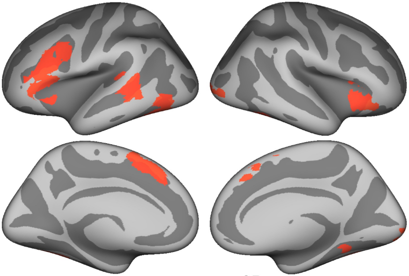
Study 1: The semantic system in children



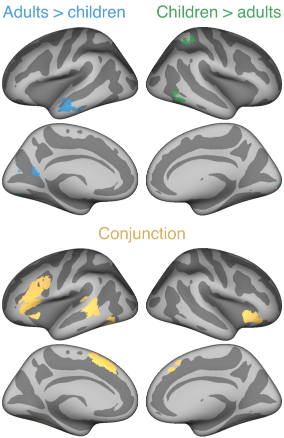
Acar et al. (2018)

Study 1: The semantic system in children

ALE map for children

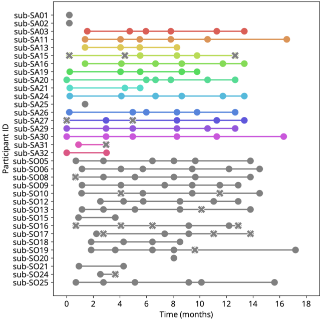


$p_{\text{cluster-FWE}} < .05$



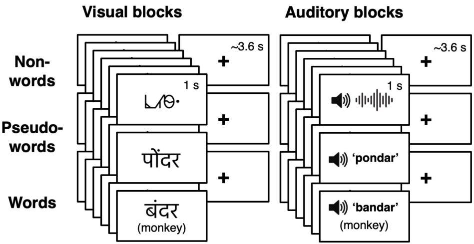
Study 2: Visual semantics in learning to read

- Longitudinal study with 15 children (5–9 years), 6 time points
- 18 month of reading instruction in Hindi/Devanagari
- MRI + standardized reading tests



Study 2: Visual semantics in learning to read

- Mini block design fMRI task
- Spoken + written non-words, pseudowords, real words
- Target detection task



See Dehaene-Lambertz et al. (2018)

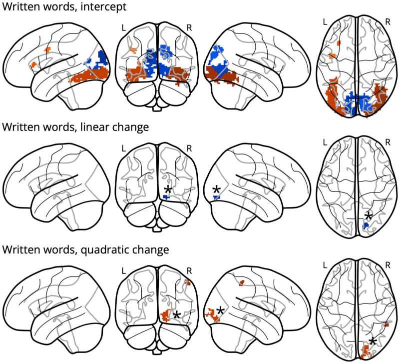
Study 2: Visual semantics in learning to read

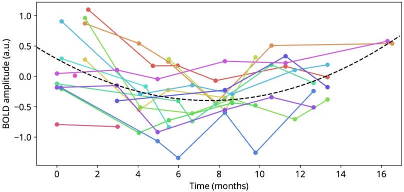
- Longitudinal analysis using linear mixed models (LMMs)
- Whole-brain univariate change in activation strength
- Multivariate change in pattern similarity and stability

```
using MixedModels
fm = @formula(beta ~ 1 + time + time2 + (1 + time + time2 | subject))
mm = fit(MixedModel, fm, df)
```

https://github.com/SkeideLab/SLANG-analysis/blob/SLANG/scripts/univariate.py
See also Chen et al. (2013); Madhyastha et al. (2018)

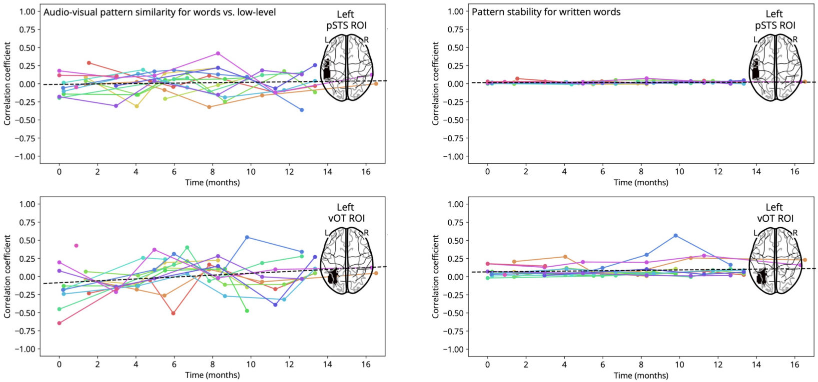
Study 2: Visual semantics in learning to read





Enge & Skeide (2024)

Study 2: Visual semantics in learning to read



Enge & Skeide (2024)

Study 3: Visual semantics in novel objects

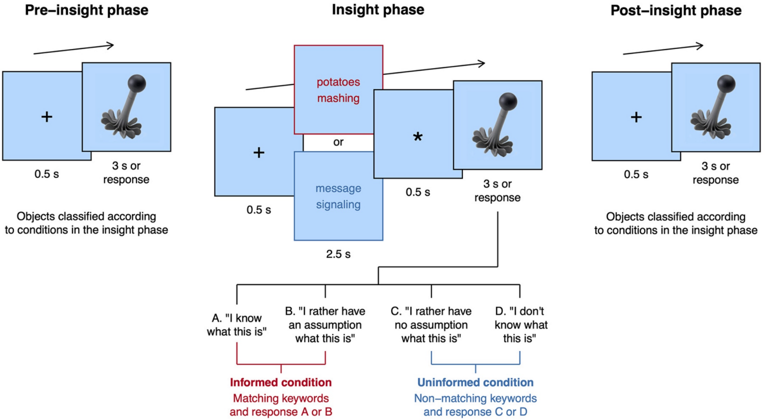
- $N = 48$ adults, 120 unfamiliar objects
- Compare informed vs. uninformed perception in each phase (before, during, after insight)

- **P1 (100–150 ms):** Early visual preprocessing
- **N170 (150–200 ms):** High-level visual preprocessing
- **N400 (400–700 ms):** Semantic processing

- Exploratory time-frequency analysis

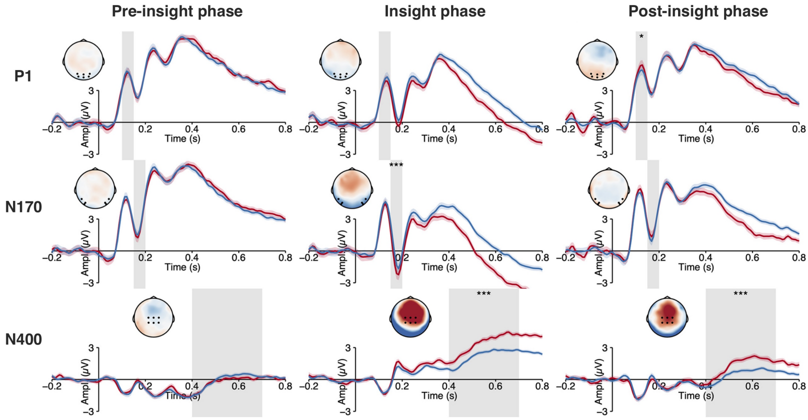
Enge et al. (2023)

Study 3: Visual semantics in novel objects



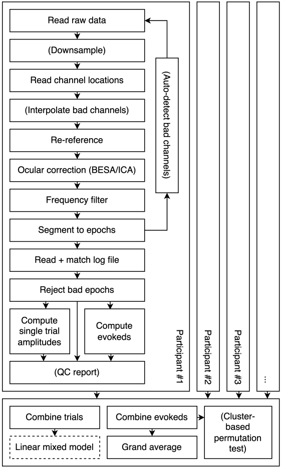
Enge et al. (2023)

Study 3: Visual semantics in novel objects



Enge et al. (2023)

Add-on: `hu-neuro-pipeline` package




frontiers in Neuroscience

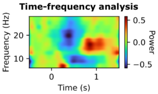
ORIGINAL RESEARCH

Group-Level EEG-Processing Pipeline for Flexible Single Trial-Based Analyses Including Linear Mixed Models

Romy Frömer, Martin Maier and Rasha Abdel Rahman

\+ MNE

\+



=

Frömer et al. (2018); hu-neuro-pipeline.readthedocs.io

Discussion

1. Semantic system in children largely adult-like by age 10
2. Learning to read increases audio-visual response patterns in left vOT cortex (*)
3. Discovering object function alters visual processing within first 200 ms

Discussion

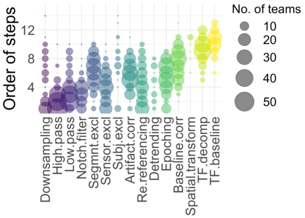
- No engagement of semantic areas from meta-analysis in reading study
- Difficult to pinpoint top-down EEG effects anatomically
- Similar mechanisms in learning to read and discovering object function?
  - Both involve linking visual features to meaning and *vice versa*
  - Both are compositional
  - But: incidental vs. diagnostic visual features
  - Phylogenetically and ontogenetically very different

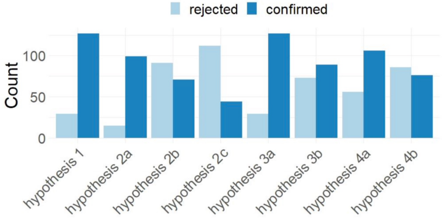
Discussion

- Limitations:
  - **Meta-analysis:** publication bias, coordinate-based approach
  - **Reading study:** sample size (!!!), intervention strength and duration, experimental design
  - **Object study:** ecological validity, localization/neural mechanisms

Discussion

- Replicability crisis, power, flexibility in cognitive neuroscience
- Generalizability to real-world tasks and people
- Need for computationally explicit theories
- Better methods can't hurt





See Botvinik-Nezer et al. (2020); Button et al. (2013); Cummins (2000); Forscher (1963); Marek et al. (2022); Open Science Collaboration (2015); Pavlov et al. (2021); Scheel et al. (2021); Simmons et al. (2011); Szucs & Ioannidis (2017); Szucs & Ioannidis (2020); Trübutschek et al. (2024); Yarkoni (2020)

Thank you







References I

Acar, F., Seurinck, R., Eickhoff, S. B., & Moerkerke, B. (2018). Assessing robustness against potential publication bias in activation likelihood estimation (ALE) meta-analyses for fMRI. *PLOS ONE*, *13*(11), e0208177. https://doi.org/10.1371/journal.pone.0208177

Binder, J. R., Desai, R. H., Graves, W. W., & Conant, L. L. (2009). Where is the semantic system? A critical review and meta-analysis of 120 functional neuroimaging studies. *Cerebral Cortex*, *19*(12), 2767–2796. https://doi.org/10.1093/cercor/bhp055

Botvinik-Nezer, R., Holzmeister, F., Camerer, C. F., Dreber, A., Huber, J., Johannesson, M., Kirchler, M., Iwanir, R., Mumford, J. A., Adcock, R. A., Avesani, P., Baczkowski, B. M., Bajracharya, A., Bakst, L., Ball, S., Barilari, M., Bault, N., Beaton, D., Beitner, J., . . . Schonberg, T. (2020). Variability in the analysis of a single neuroimaging dataset by many teams. *Nature*, *582*(7810), 84–88. https://doi.org/10.1038/s41586-020-2314-9

Button, K. S., Ioannidis, J. P. A., Mokrysz, C., Nosek, B. A., Flint, J., Robinson, E. S. J., & Munafò, M. R. (2013). Power failure: Why small sample size undermines the reliability of neuroscience. *Nature Reviews Neuroscience*, *14*(5), 365–376. https://doi.org/10.1038/nrn3475

Chen, G., Saad, Z. S., Britton, J. C., Pine, D. S., & Cox, R. W. (2013). Linear mixed-effects modeling approach to fMRI group analysis. *NeuroImage*, *73*, 176–190. https://doi.org/10.1016/j.neuroimage.2013.01.047

Cummins, R. (2000). "How does it work?" versus "What are the laws?": Two conceptions of psychological explanation. In *Explanation and Cognition* (pp. 117–144). MIT Press.

References II

Dehaene-Lambertz, G., Monzalvo, K., & Dehaene, S. (2018). The emergence of the visual word form: Longitudinal evolution of category-specific ventral visual areas during reading acquisition. *PLOS Biology*, *16*(3), 1–34. https://doi.org/10.1371/journal.pbio.2004103

Deniz, F., Nunez-Elizalde, A. O., Huth, A. G., & Gallant, J. L. (2019). The representation of semantic information across human cerebral cortex during listening versus reading is invariant to stimulus modality. *Journal of Neuroscience*, *39*(39), 7722–7736. https://doi.org/10.1523/JNEUROSCI.0675-19.2019

DiCarlo, J. J., Zoccolan, D., & Rust, N. C. (2012). How does the brain solve visual object recognition? *Neuron*, *73*(3), 415–434. https://doi.org/10.1016/j.neuron.2012.01.010

Enge, A., Abdel Rahman, R., & Skeide, M. A. (2021). A meta-analysis of fMRI studies of semantic cognition in children. *NeuroImage*, *241*, 118436. https://doi.org/10.1016/j.neuroimage.2021.118436

Enge, A., & Skeide, M. A. (2024). *Tracking the neural correlates of learning to read with dense-sampling fMRI* [Unpublished Manuscript]. https://github.com/alexenge/thesis/blob/main/papers/enge2024.pdf

Enge, A., Süß, F., & Abdel Rahman, R. (2023). Instant effects of semantic information on visual perception. *Journal of Neuroscience*, *43*(26), 4896–4906. https://doi.org/10.1523/JNEUROSCI.2038-22.2023

Felleman, D. J., & Van Essen, D. C. (1991). Distributed hierarchical processing in the primate cerebral cortex. *Cerebral Cortex*, *1*(1), 1–47. https://doi.org/10.1093/cercor/1.1.1-a

Forscher, B. K. (1963). Chaos in the brickyard. *Science*, *142*(3590), 339–339. https://doi.org/10.1126/science.142.3590.339.a

References III

Frömer, R., Maier, M., & Abdel Rahman, R. (2018). Group-level EEG-processing pipeline for flexible single trial-based analyses including linear mixed models. *Frontiers in Neuroscience*, *12*, 48. https://doi.org/10.3389/fnins.2018.00048

Huth, A. G., de Heer, W. A., Griffiths, T. L., Theunissen, F. E., & Gallant, J. L. (2016). Natural speech reveals the semantic maps that tile human cerebral cortex. *Nature*, *532*(7600), 453–458. https://doi.org/10.1038/nature17637

Madhyastha, T., Peverill, M., Koh, N., McCabe, C., Flournoy, J., Mills, K., King, K., Pfeifer, J., & McLaughlin, K. A. (2018). Current methods and limitations for longitudinal fMRI analysis across development. *Developmental Cognitive Neuroscience*, *33*, 118–128. https://doi.org/gdz7rh

Marek, S., Tervo-Clemmens, B., Calabro, F. J., Montez, D. F., Kay, B. P., Hatoum, A. S., Donohue, M. R., Foran, W., Miller, R. L., Hendrickson, T. J., Malone, S. M., Kandala, S., Feczko, E., Miranda-Dominguez, O., Graham, A. M., Earl, E. A., Perrone, A. J., Cordova, M., Doyle, O., . . . Dosenbach, N. U. F. (2022). Reproducible brain-wide association studies require thousands of individuals. *Nature*, *603*(7902), 654–660. https://doi.org/10.1038/s41586-022-04492-9

Open Science Collaboration. (2015). Estimating the reproducibility of psychological science. *Science*, *349*(6251), aac4716. https://doi.org/10.1126/science.aac4716

Ouyang, G., Sommer, W., & Zhou, C. (2015). A toolbox for residue iteration decomposition (RIDE)—A method for the decomposition, reconstruction, and single trial analysis of event related potentials. *Journal of Neuroscience Methods*, *250*, 7–21. https://doi.org/10.1016/j.jneumeth.2014.10.009

References IV

Pavlov, Y. G., Adamian, N., Appelhoff, S., Arvaneh, M., Benwell, C. S. Y., Beste, C., Bland, A. R., Bradford, D. E., Bublatzky, F., Busch, N. A., Clayson, P. E., Cruse, D., Czeszumski, A., Dreber, A., Dumas, G., Ehinger, B., Ganis, G., He, X., Hinojosa, J. A., . . . Mushtaq, F. (2021). #EEGManyLabs: Investigating the replicability of influential EEG experiments. *Cortex*, *144*, 213–229. https://doi.org/10.1016/j.cortex.2021.03.013

Scheel, A. M., Tiokhin, L., Isager, P. M., & Lakens, D. (2021). Why hypothesis testers should spend less time testing hypotheses. *Perspectives on Psychological Science*, *16*(4), 744–755. https://doi.org/10.1177/1745691620966795

Simmons, J. P., Nelson, L. D., & Simonsohn, U. (2011). False-positive psychology: Undisclosed flexibility in data collection and analysis allows presenting anything as significant. *Psychological Science*, *22*(11), 1359–1366. https://doi.org/10.1177/0956797611417632

Szucs, D., & Ioannidis, J. P. (2020). Sample size evolution in neuroimaging research: An evaluation of highly-cited studies (1990-2012) and of latest practices (2017-2018) in high-impact journals. *NeuroImage*, *221*, 117164. https://doi.org/10.1016/j.neuroimage.2020.117164

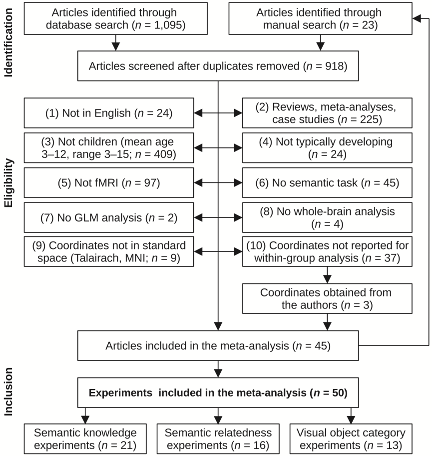
Szucs, D., & Ioannidis, J. P. A. (2017). Empirical assessment of published effect sizes and power in the recent cognitive neuroscience and psychology literature. *PLOS Biology*, *15*(3), e2000797. https://doi.org/10.1371/journal.pbio.2000797

References V

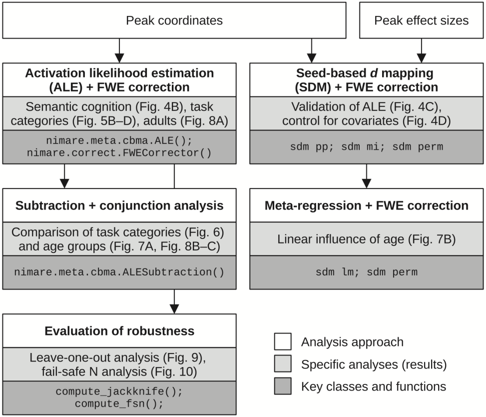
Trübutschek, D., Yang, Y.-F., Gianelli, C., Cesnaite, E., Fischer, N. L., Vinding, M. C., Marshall, T. R., Algermissen, J., Pascarella, A., Puoliväli, T., Vitale, A., Busch, N. A., & Nilsonne, G. (2024). EEGManyPipelines: A Large-scale, Grassroots Multi-analyst Study of Electroencephalography Analysis Practices in the Wild. *Journal of Cognitive Neuroscience*, *36*(2), 217–224. https://doi.org/10.1162/jocn_a_02087

Yarkoni, T. (2020). The generalizability crisis. *Behavioral and Brain Sciences*, *45*, e1. https://doi.org/10.1017/S0140525X20001685

Study 1: The semantic system in children

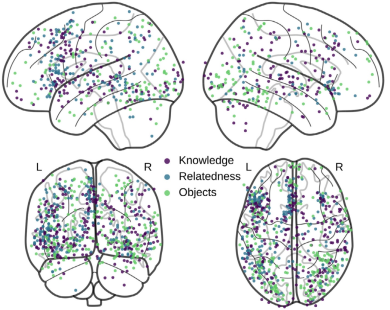


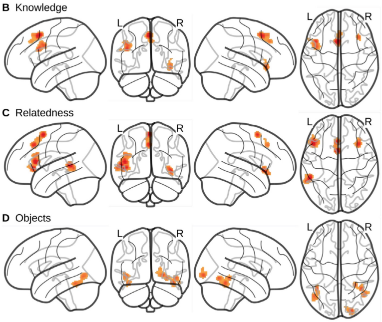
Study 1: The semantic system in children



Enge et al. (2021)

Study 1: The semantic system in children

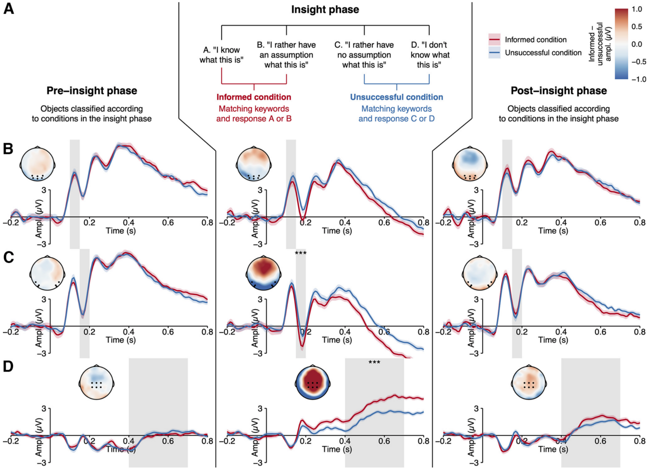




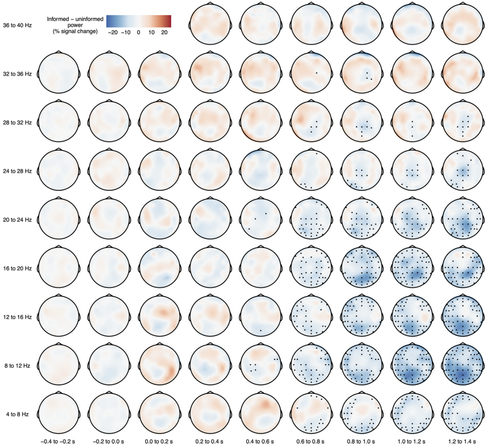
Enge et al. (2021)

Study 2: Visual semantics in learning to read

Study 3: Visual semantics in novel objects

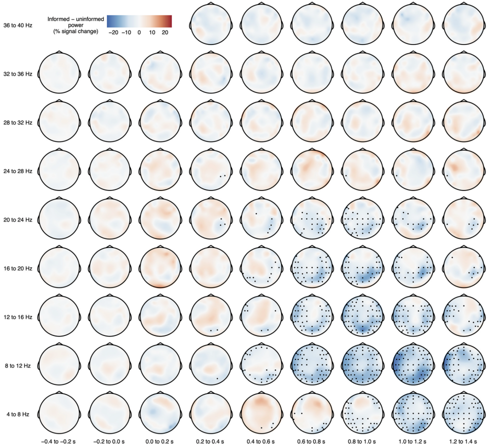


Study 3: Visual semantics in novel objects



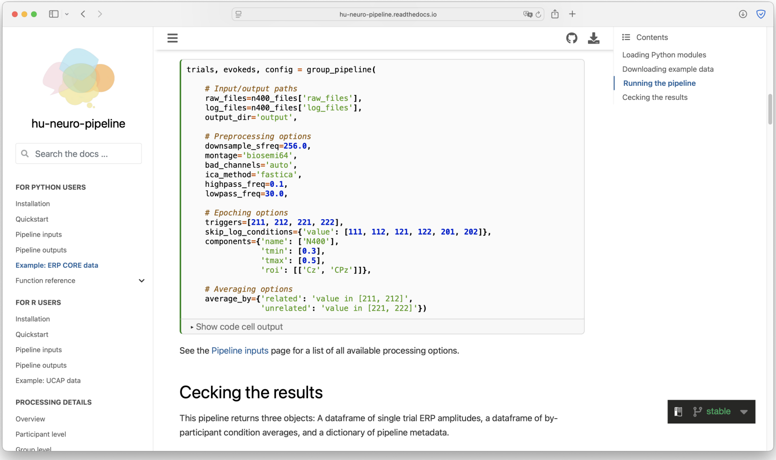
Enge et al. (2023)

Study 3: Visual semantics in novel objects



Enge et al. (2023)

Add-on: `hu-neuro-pipeline` package



hu-neuro-pipeline.readthedocs.io

hu-neuro-pipeline

Search the docs ...


```python
trials, evokeds, config = group_pipeline(

    # Input/output paths
    raw_files=n400_files['raw_files'],
    log_files=n400_files['log_files'],
    output_dir='output',

    # Preprocessing options
    downsample_sfreq=256.0,
    montage='biosemi64',
    bad_channels='auto',
    ica_method='fastica',
    highpass_freq=0.1,
    lowpass_freq=30.0,

    # Epoching options
    triggers=[211, 212, 221, 222],
    skip_log_conditions={'value': [111, 112, 121, 122, 201, 202]},
    components={'name': ['N400'],
                'tmin': [0.3],
                'tmax': [0.5],
                'roi': [['Cz', 'CPz']]},

    # Averaging options
    average_by={'related': 'value in [211, 212]',
                'unrelated': 'value in [221, 222]'})
```

▸ Show code cell output

See the Pipeline inputs page for a list of all available processing options.

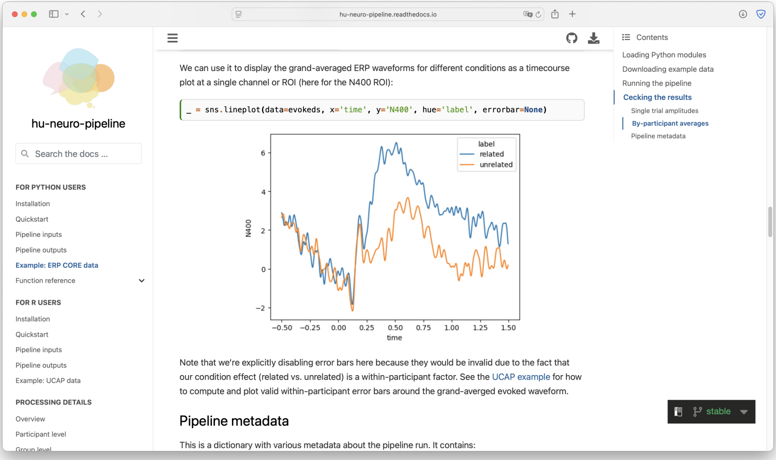
Cecking the results

This pipeline returns three objects: A dataframe of single trial ERP amplitudes, a dataframe of by-participant condition averages, and a dictionary of pipeline metadata.

Contents

stable

Add-on: `hu-neuro-pipeline` package



Add-on: hu-neuro-pipeline package

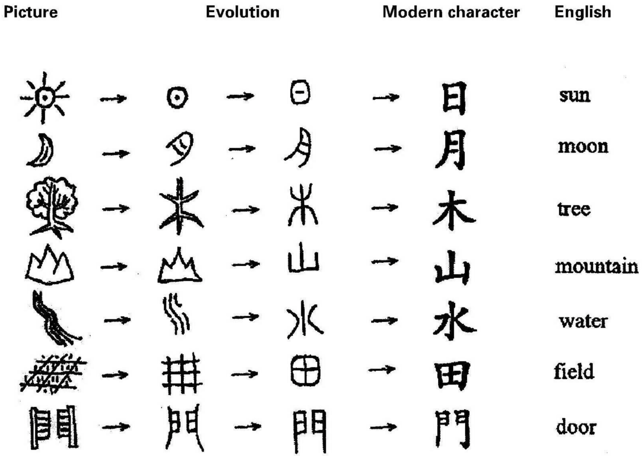
```r
# Load packages
library("reticulate")
pipeline <- import("pipeline")

# Download example data
ucap_files <- pipeline$datasets$get_ucap()

# Run the pipeline
res <- pipeline$group_pipeline(
  raw_files = ucap_files$raw_files,
  log_files = ucap_files$log_files,
  besa_files = ucap_files$besa_files,
  output_dir = "output",
  triggers = c(201:208, 211:218),
  components = list(
    "name" = list("N2", "P3b"),
    "tmin" = list(0.25, 0.4),
    "tmax" = list(0.35, 0.55),
    "roi" = list(
      c("FC1", "FC2", "C1", "C2", "Cz"),
      c("CP3", "CP1", "CPz", "CP2", "CP4", "P3", "Pz", "P4", "PO3", "POz", "PO4")
    )
  ),
  average_by = list(blurr = "n_b == 'blurr'", normal = "n_b == 'normal'")
)
```

Add-on: `hu-neuro-pipeline` package

- **Homepage:** hu-neuro-pipeline.readthedocs.io
- **Slides:** github.com/alexenge/hu-neuro-pipeline-workshop
- **EEG analysis course:** alexenge.github.io/intro-to-eeg
- **Speech artifact correction:** eeg-ride.readthedocs.io

Enge et al. (2023); Frömer et al. (2018); Ouyang et al. (2015)

Discussion



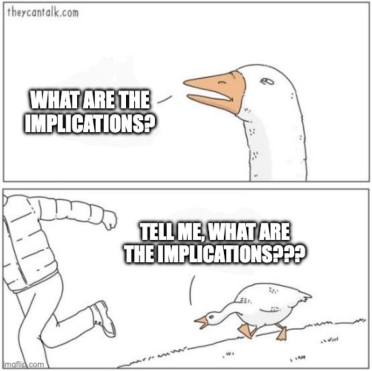
Picture
Evolution
Modern character
English
日 sun
月 moon
木 tree
山 mountain
水 water
田 field
門 door

Discussion

"And Nikos Logothetis had a really unique setup at that time in Tubingen and published a paper around 2001 where he recorded simultaneously fMRI local field potentials in single neurons. [...] And so we ended up doing a project where we ran patients first in a version of the virtual navigation task using fMRI and then recorded single neurons and local field potentials when they did that task. [...] And that ended up being a really complicated, unsatisfying project, because basically what we found was the answer that no one really wanted, that the areas where we saw activation in the patients prior to undergoing implantation didn't match up very well with what we saw with single neurons or the local field potential. And really what we found was weak evidence for a correlation in some of the surrounding cortical areas for low frequency oscillation power increasing with the bold signal. [...] And that was really all we found. **So, if anything, we would conclude that single neurons don't relate well to fMRI, at least in the medial temporal lobe, and there's a weak correlation with the local field potential.** And we submitted that paper at Nature. It got reviewed and rejected, and just reviewers didn't like it because Logothetis had already solved the problem, right? We already know that the bold signal tells us mostly about gamma oscillations in the local field potential, but still a little bit about single neurons. We already know that, so why are you trying to tell us something different? And even if you are, Logothetis could do it better because he could do it simultaneously. **So there just wasn't a lot of enthusiasm, and it was like the result that no one wanted, which is fMRI is really difficult to interpret, and it depends on what brain region you're in, what response you're going to get. And one thing I've learned in cognitive neuroscience is people don't tend to like complicated answers.** [...] The bold signal is not always reflected in electrophysiological activity. It's complicated, right? And I think it was one of these examples where the story was sort of, it didn't fit with the *zeitgeist*, and we didn't exactly know what to do with it either. And so I ended up after my postdoc taking a faculty position at UC Davis, where I didn't end up doing a lot with that line of research, but I continued invasive recordings and then spent a lot more time working with fMRI and then invested a lot more time in studies related to fMRI."

From BJKS Podcast: 97. Arne Ekstrom: *Spatial navigation, memory, and invasive recordings in humans*, May 24, 2024. https://bjks.buzzsprout.com/1390924/episodes/15118255-97-arne-ekstrom-spatial-navigation-memory-and-invasive-recordings-in-humans

Discussion



https://jamesheathers.medium.com/i-quit-be062295f638
https://slimemoldtimemold.com