Decoding the Infant Mind: Multichannel Pattern Analysis (MCPA) using fNIRS

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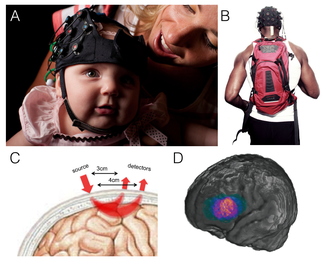
Background

Functional Near Infrared Spectroscopy (fNIRS)

- Neuroimaging method that measures hemodynamic changes over time (% change in blood oxygenation), analogous to functional MRI.
- Lower resolution than fMRI (~3 cm diameter channels), but higher spatial specificity than EEG (no conduction of signal over the scalp).



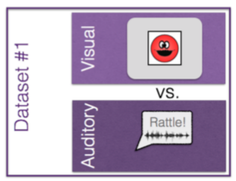
A. fNIRS is silent and robust to motion, suitable for infant research.
B. fNIRS device requires no special environment or safety precautions (unlike MRI) and can be highly portable (for some hardware).
C. fNIRS measures the scatter of infrared light from one site on the scalp (source), through cortical tissue, to another nearby site (detector).
D. Spatial specificity allows MRI-like cortical localization of signal, albeit at lower spatial resolution and without access to deep brain tissues.

Multivoxel pattern analysis & Neural decoding

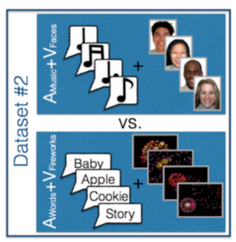
- Multivoxel pattern analysis (MVPA) asks whether the *pattern* of BOLD signals can discriminate between conditions.
- MVPA shifts the focus from mean activation differences in a region to the information contained within patterns of brain activity.
- Multi*channel* pattern analysis applies the same multivariate principles as MVPA to fNIRS data to broaden application to infants, paradigms requiring movement, and other studies outside the MRI environment.

fNIRS Datasets: *Two previous infant studies*

Dataset #1: n=19 infants, passively observing two single sensory modality stimulus types
Visual: a cartoon smiley face
Auditory: a toy sound (rattle or honk)
Source: Emberson et al., 2015



Dataset #2: n=18 infants, passively observing two multi-sensory stimulus types
AV-1: music and a photographic face
AV-2: a spoken word and fireworks
Source: Emberson et al., under review



Acknowledgments

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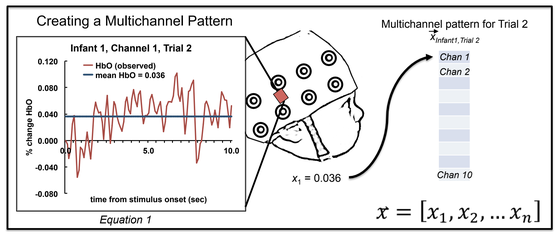
Decoding with MCPA

Multichannel Pattern Analysis

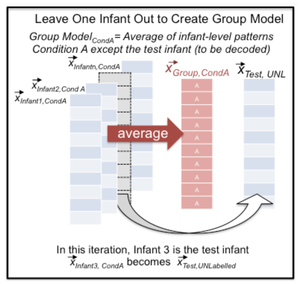
Equation 1: Each channel is represented by the average % change in oxygenated hemoglobin (HbO) in a given time window.

$$x_{chan} = \frac{1}{t}\sum_{i=1}^{t} HbO_{chan,i}$$



Equation 2: Multichannel patterns are averaged across trials (within condition) for each infant. For example, given *r* trials in Condition A:

$$x_{Infant,Cond} = \frac{1}{r}\sum_{j=1}^{r} x_{Infant\ n,Cond\ A,Trial\ j}$$



These infant-level condition patterns are then averaged across infants to produce a **Group Model.**

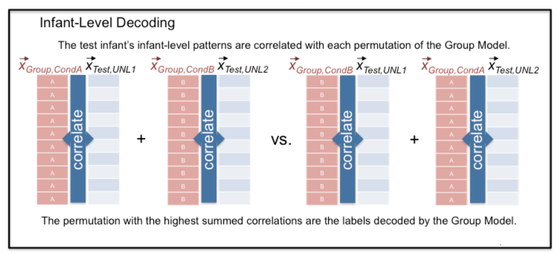
One infant is excluded from the group to serve as a **Test Infant**

This procedure is repeated once for each infant to serve as test infant (*n*-fold cross validation).

Infant-Level Decoding

For each infant, we test which permutation of the two condition labels best matches the two multichannel patterns from the group model

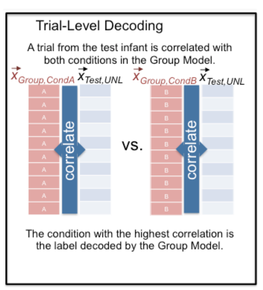
$$\text{corr}(x_{Group,CondA}, x_{Test,Unl2}) + \text{corr}(x_{Group,CondB}, x_{Test,Unl1})$$
vs.
$$\text{corr}(x_{Group,CondA}, x_{Test,Unl1}) + \text{corr}(x_{Group,CondB}, x_{Test,Unl2})$$



Trial-Level Decoding

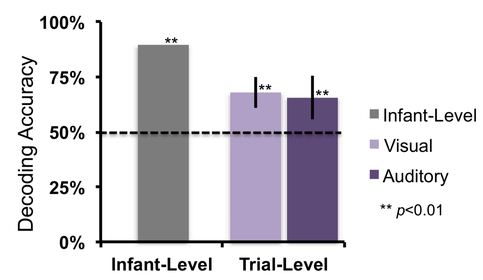
For each infant, we examine each trial one-at-a-time to see which of the two multichannel patterns from the group model is the best fit:

$$\text{corr}(x_{Group,CondA}, x_{Test,Unl})$$
vs.
$$\text{corr}(x_{Group,CondB}, x_{Test,Unl})$$



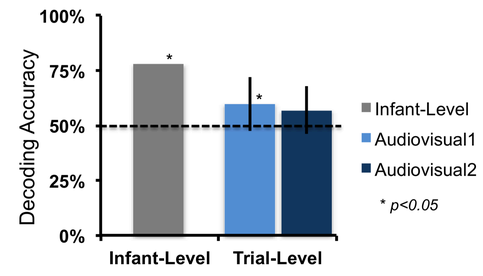
Decoding Results

Dataset #1: Visual vs. Auditory modality



Both infant- and trial-level decoding were significantly above chance.

Dataset #2: Integrated Audiovisual modalities

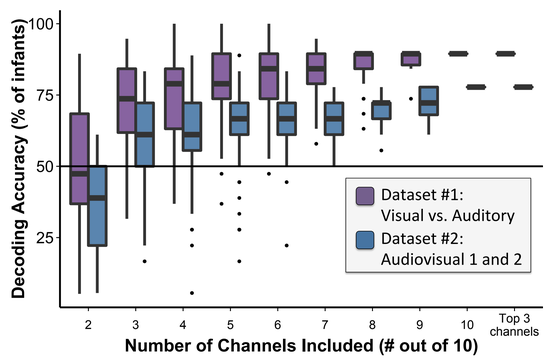


Infant-level decoding was significantly above chance. Trial-level decoding was above chance in one condition, but only marginal in the other.

Are all 10 channels necessary for accurate decoding?

We repeat the MCPA procedure for infant-level decoding with subsets of channels (e.g., decoding with only 5 channels at a time instead of all 10).

For each subset size, there are 10-pick-*k* ($_{10}C_k$) combinations of *k* channels. Infant-level decoding accuracy for each subset is computed and the box and whisker plots show decoding accuracy for every combination of channels within each subset size (along the horizontal-axis).



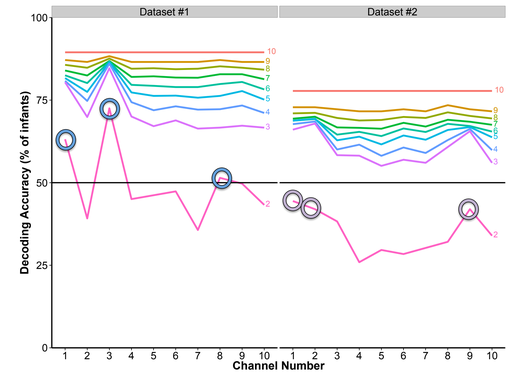
Average decoding performance improves in both datasets with the inclusion of more channels. However, even relatively small subsets (e.g., 3 or 4 channels) have some combinations that decode with high accuracy.

In the next section, we ask which channels provide the best decoding performance across many combinations and subset sizes. The performance of the Top 3 channels taken together is shown in this figure.

Spatial Inference

Are all channels equally informative?

Each channel can be evaluated by its average performance across all subsets of a given size:



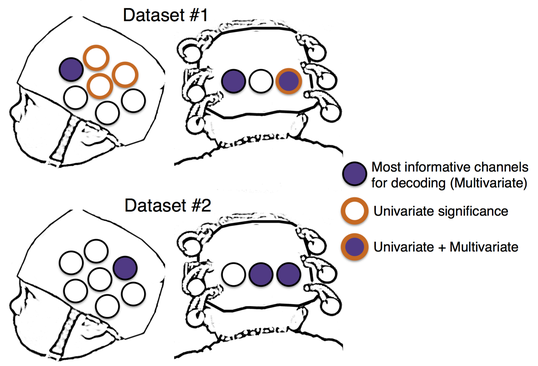
Dataset #1: Channels 1, 3, and 8 show best average performance
Dataset #2: Channels 1, 2, and 9 show best average performance

For each dataset, these channels create a pattern with a subset size *k*=3, and decoding accuracy is equal to the decoding accuracy for all 10 channels (see subset size figure to the left).

Comparison with Univariate Analysis

Univariate analyses were performed on each dataset (see Emberson et al., 2015 and Emberson et al., under review for details).

In Dataset #1, channels which produced significant univariate results are circled in orange. These channels differ from the Top 3 channels in the MCPA analyses.



In Dataset #2, none of the channels survived the univariate analysis after correction for multiple comparisons.

Conclusions

- We demonstrate significant decoding of the infant brain using fNIRS.
- Subset analyses show:
  - benefits of a greater number of channels (multivariate aspect)
  - differential informativeness of each channel (spatial aspect)
- New questions that can now be answered which were previously inaccessible to univariate fNIRS or multivariate fMRI

All code to perform 2-condition MCPA is publicly available here:
http://teammcpa.github.io/EmbersonZinszerMCPA/

References: Emberson, L. L., Richards, J. E., & Aslin, R. N. (2015). Top-down modulation in the infant brain: Learning-induced expectations rapidly affect the sensory cortex at 6-months. *Proceedings of the National Academy of Sciences, 112*(30), 9585-9590.