Differential neural responses in high-level visual cortex explain categorization behavior

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How do we categorize ambiguous images?

How do we categorize ambiguous images?

What is this?

A Caribbean island?

A face?

A hand?

How does visual cortex support this categorization?

What is this?

A Caribbean island?

A face?

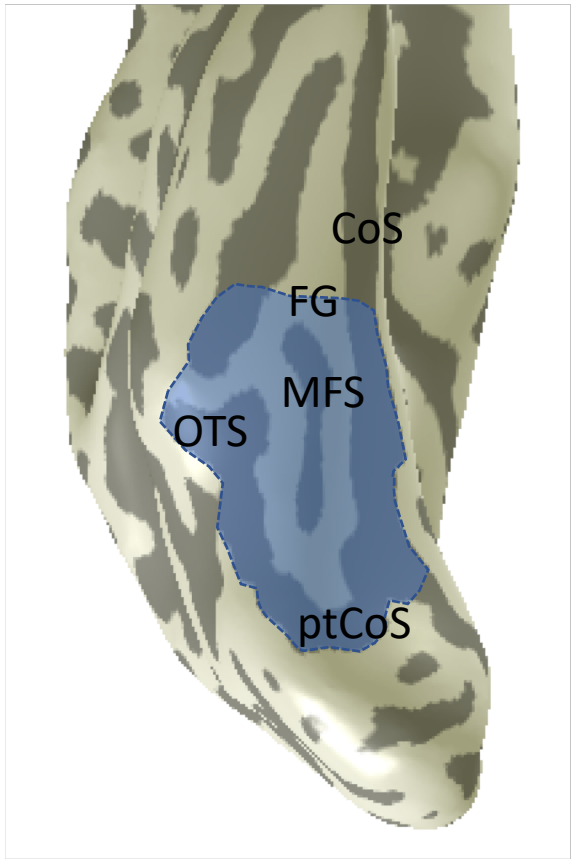
A hand?

A long line of research shows that ventral temporal cortex supports the perceptual ability to categorize visual images

Brain directions: Inflated cortex with view of the ventral occipital and temporal lobe

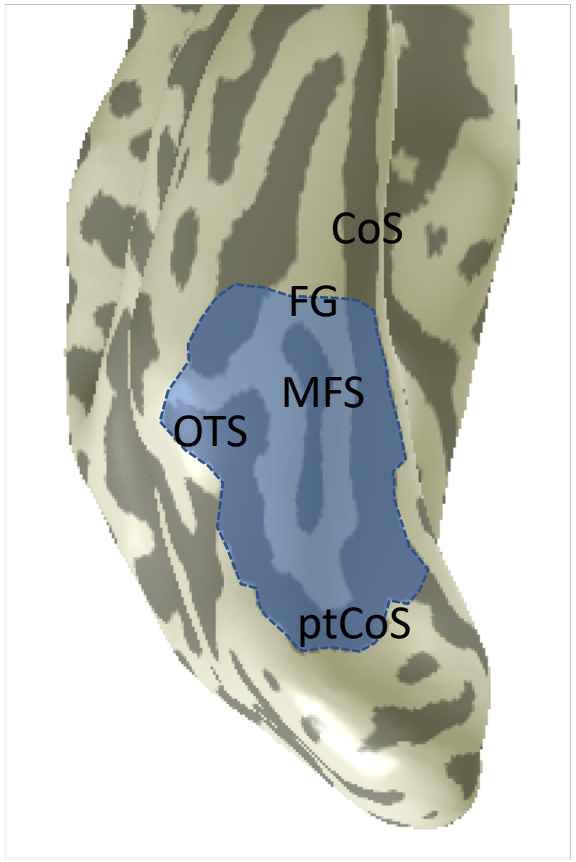
dark gray = sulci
light gray = gyri

Ventral temporal cortex (VTC) is an anatomical area that can be defined by a series of anatomical landmarks



CoS = Collateral sulcus
FG = Fusiform gyrus
MFS = Mid-fusiform sulcus
OTS = Occipital temporal sulcus
ptCoS = posterior transverse collateral sulcus

VTC achieves efficient categorization by having small specialized clusters for different visual categories – e.g. faces



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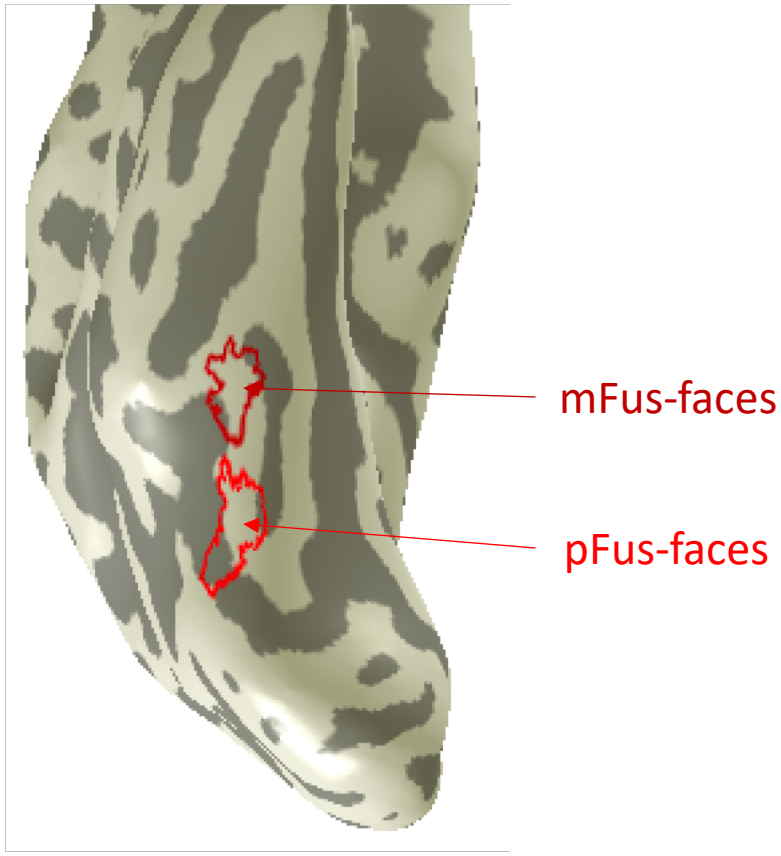
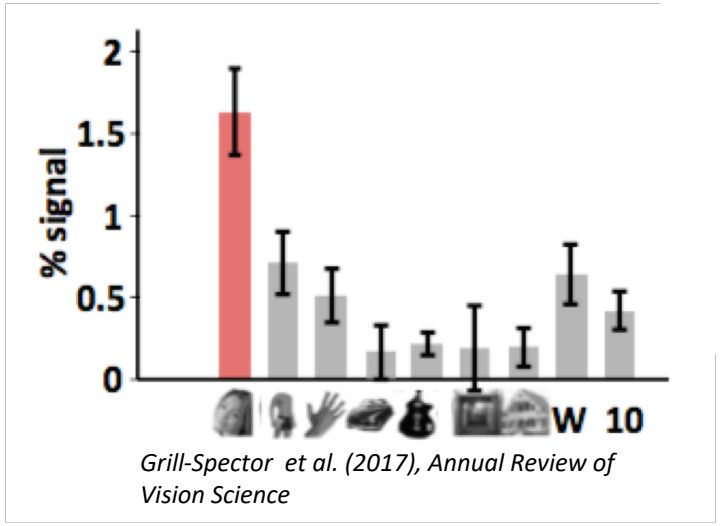


faces > other categories, t = 3

These regions are referred to as face-selective because they exhibit higher fMRI signals to faces than other stimuli

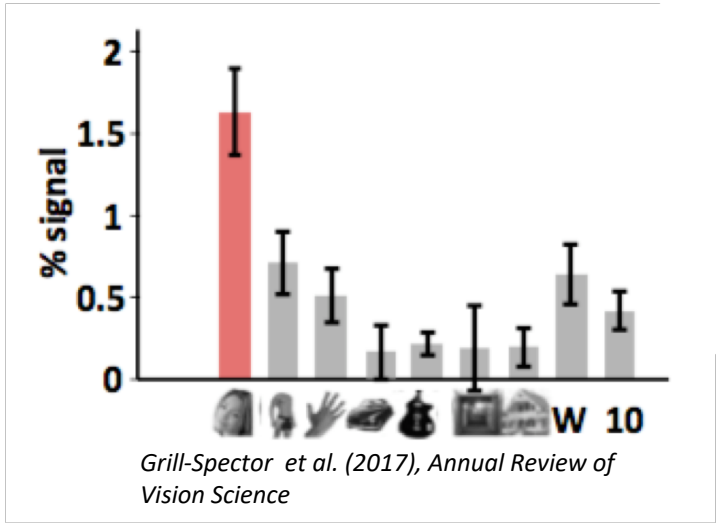


Grill-Spector et al. (2017), Annual Review of Vision Science

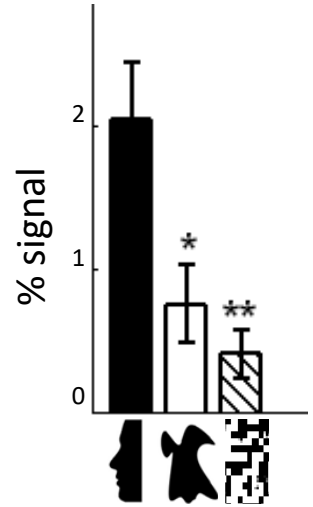
faces > other categories, t = 3

These regions show higher signals for faces across stimulus formats

faces > other categories, t > 3
limbs > other categories, t > 3

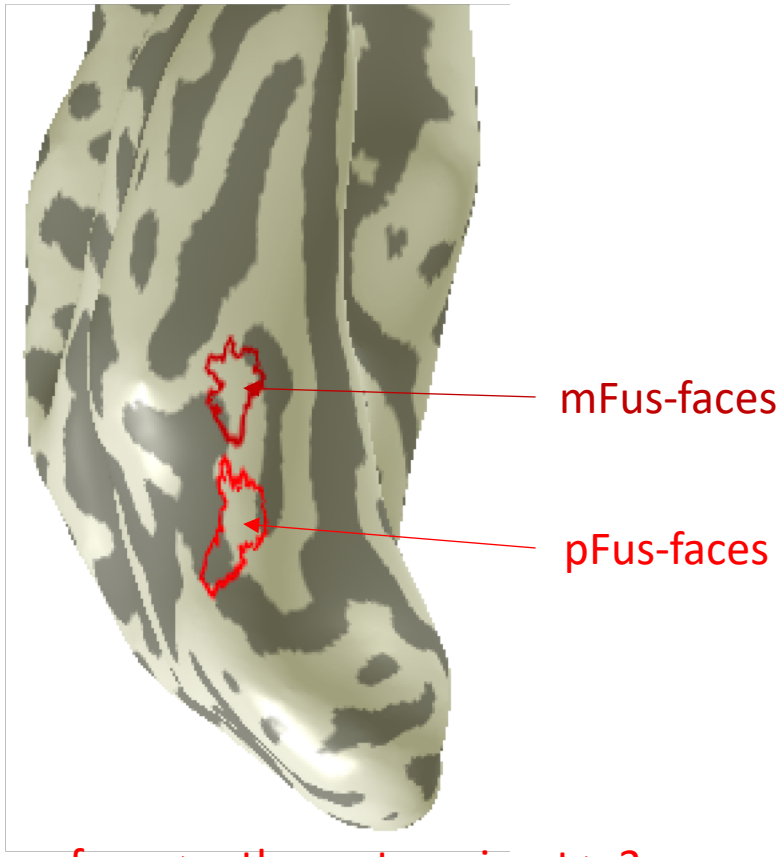


Grill-Spector et al. (2017), Annual Review of Vision Science

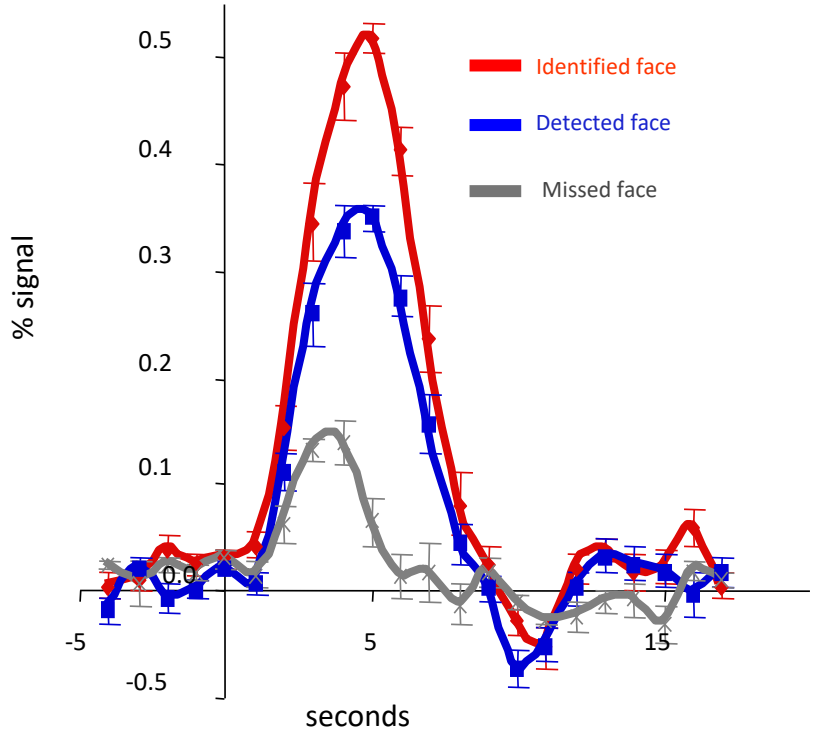


Davidenko et al. (2011), Human Brain Mapping

Responses in face-selective regions are correlated with the perception of faces

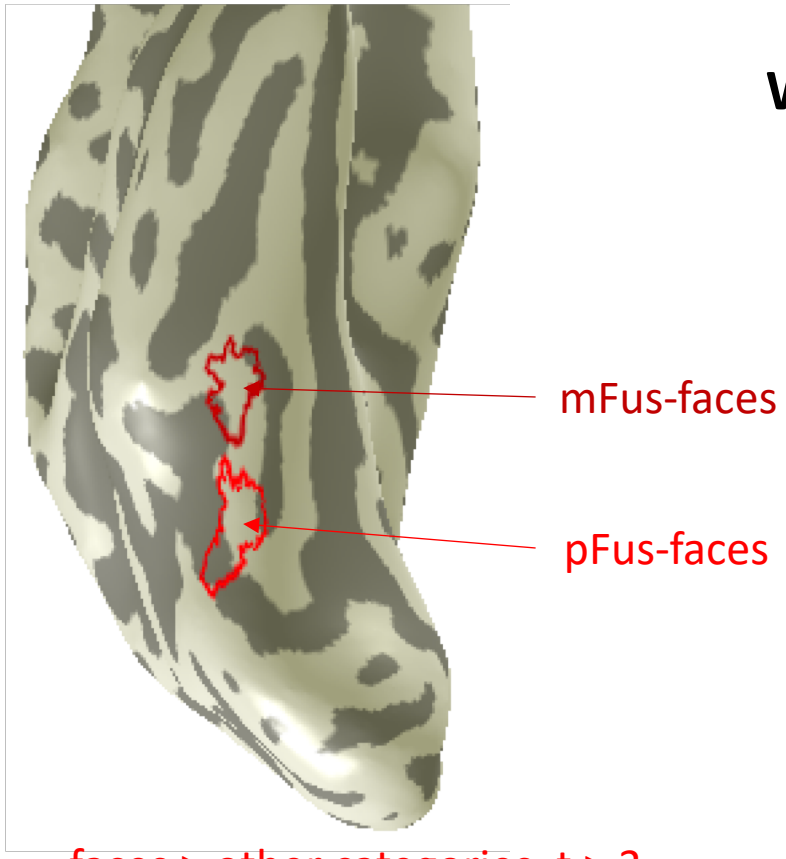


faces > other categories, t > 3



Grill-Spector et al. (2004), Nature Neuroscience

Studies so far largely investigated the role of category-selective regions in perceiving their preferred category



faces > other categories, t > 3

We were interested in building on these findings:

- **using carefully controlled stimuli**
- **that show ambiguous images**
- **to investigate between-category categorization**

Another domain-specific area is OTS-bodies, which shows the highest signal to bodies

faces > other categories, t > 3
limbs > other categories, t > 3

We were interested in building on these findings:

- **using carefully controlled stimuli**
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Another domain-specific area is OTS-bodies, which shows the highest signal to bodies

We were interested in building on these findings:

- **using carefully controlled stimuli**
- **that show ambiguous images**
- **to investigate between-category categorization**
- **within face- and body-selective regions in VTC**

Research questions

(1) Does perceptual categorization correlate with neural responses in mFus-faces, pFus-faces and OTS-bodies?

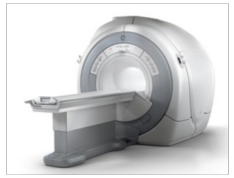
(2) Does the combination of multiple regions processing faces and hands explain perceptual categorization better than one by itself?

Morphed face silhouettes to hands silhouettes, chose 5 morphing steps

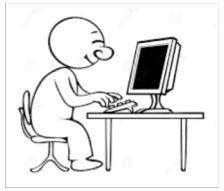
Experimental design

Stimulus calibration

fMRI blocked experiment



Behavioral categorization task



Model linking fMRI responses to behavioral categorization

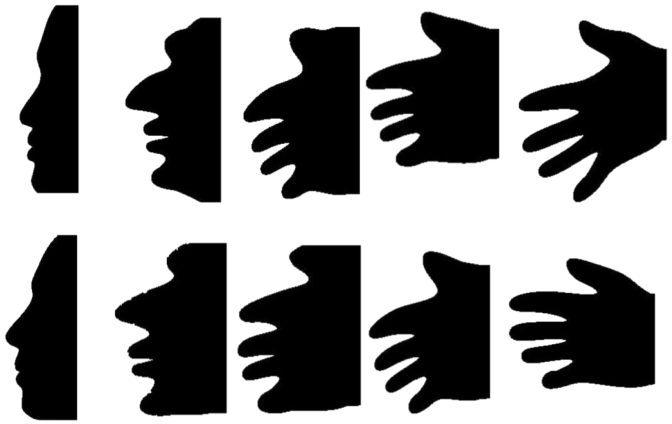
We calibrated the stimulus set on mechanical Turk in a large group of subjects

(1) Morph space normalization

N = 60 stimulus morphs

Purpose: perceptually equidistant morph steps

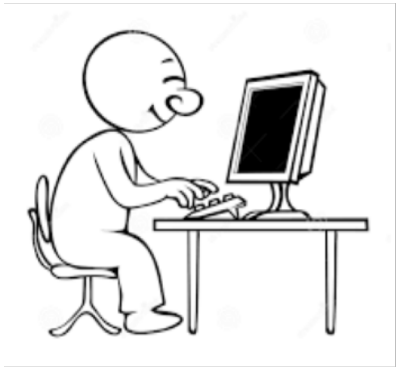
(2) Dissimilarity adjustment between stimulus exemplars

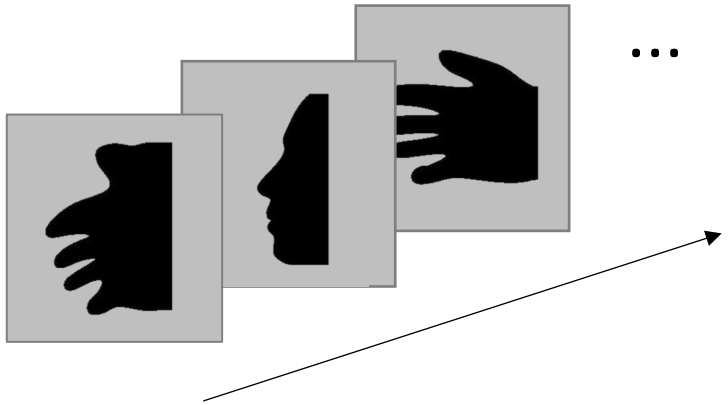


Purpose: constant dissimilarity within each morphing level

A new group of subjects (N = 14) performed a behavioral categorization task

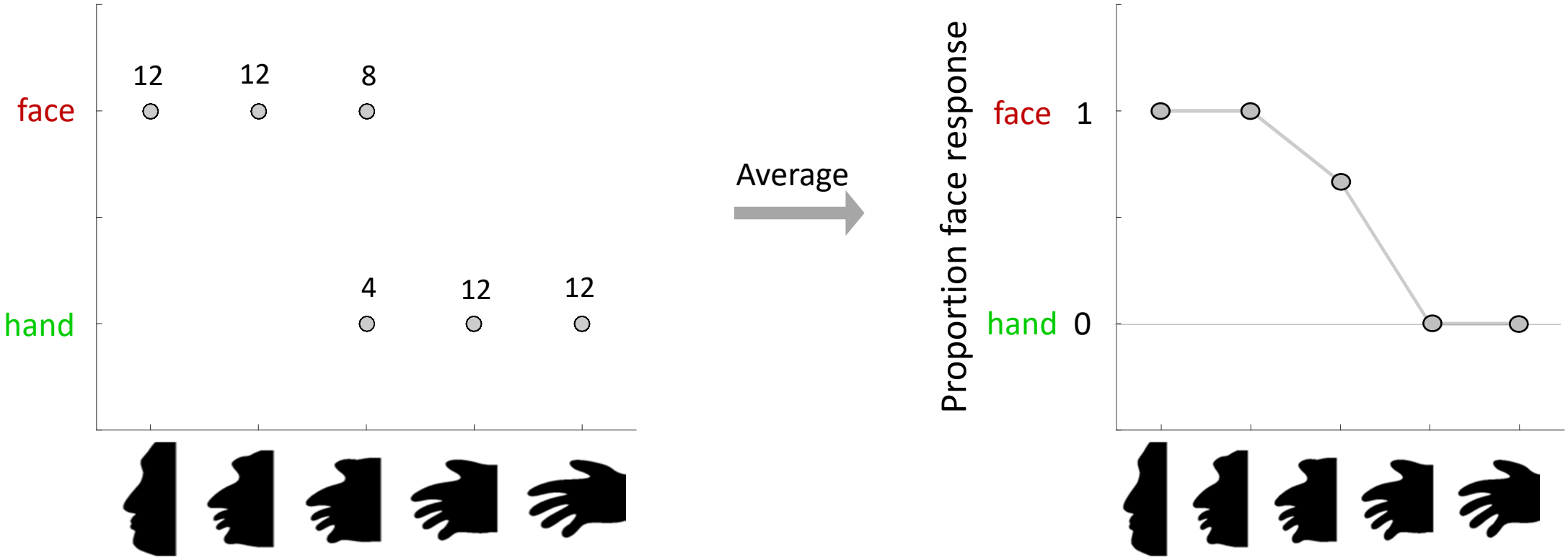
On each stimulus indicate: *Is this a face or a hand?*





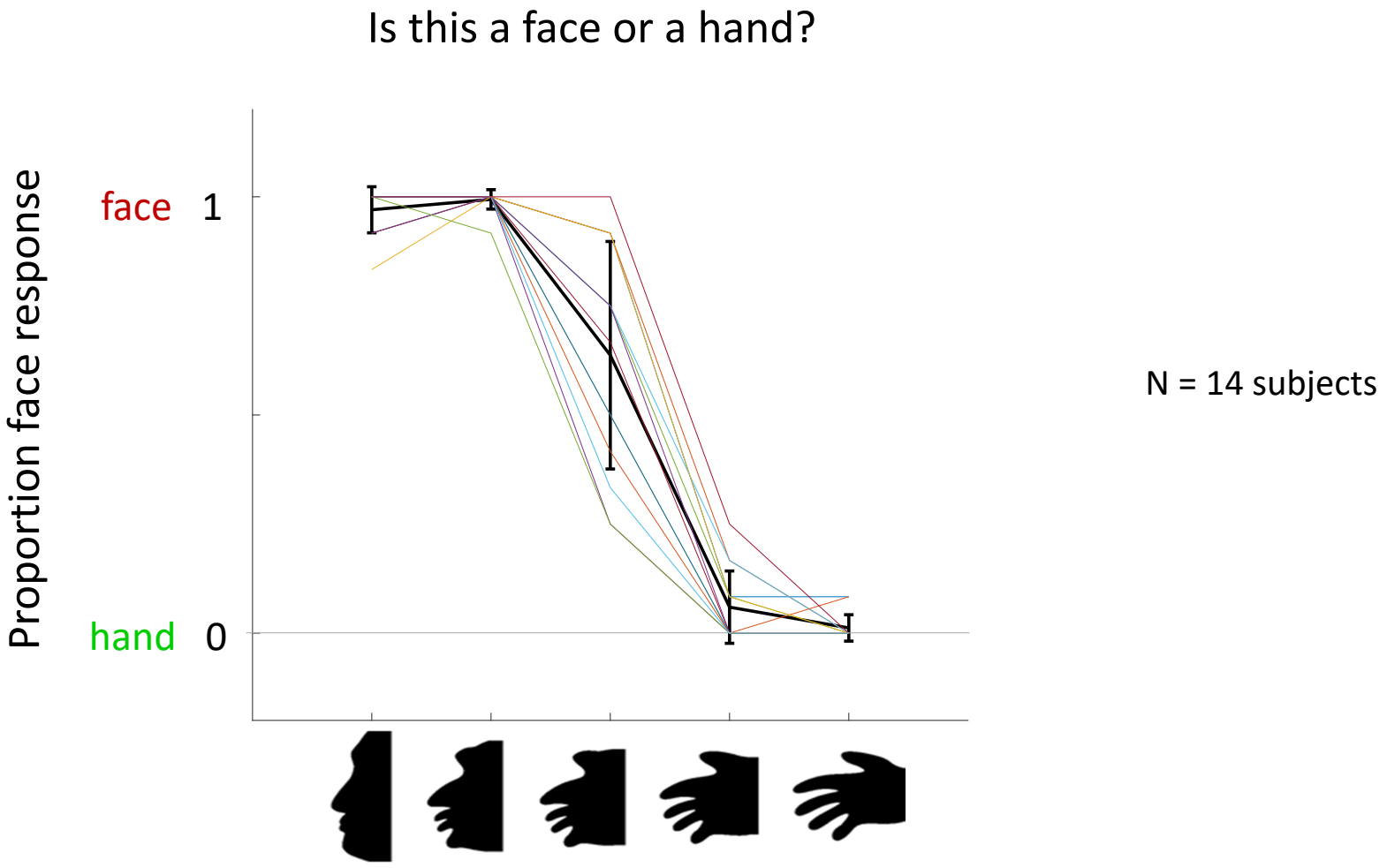
- 60 trials
- 12 different stimuli per morph level

How many times was each stimulus rated as a face or a hand? Example subject



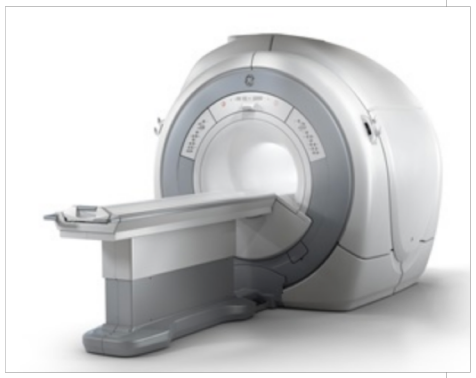
N = 60 trials

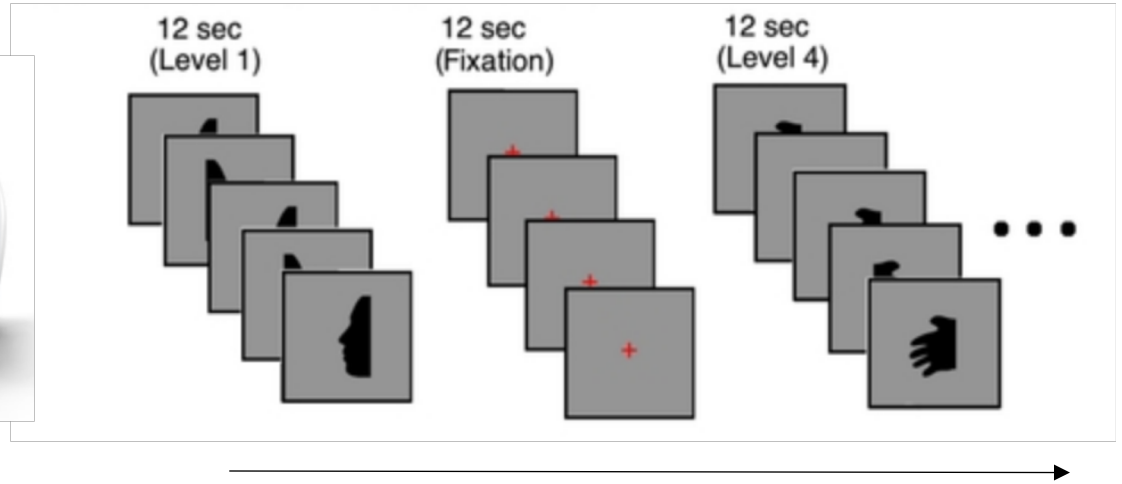
Middle morph level is perceived as ambiguous, category boundary varies across subjects



N = 14 subjects

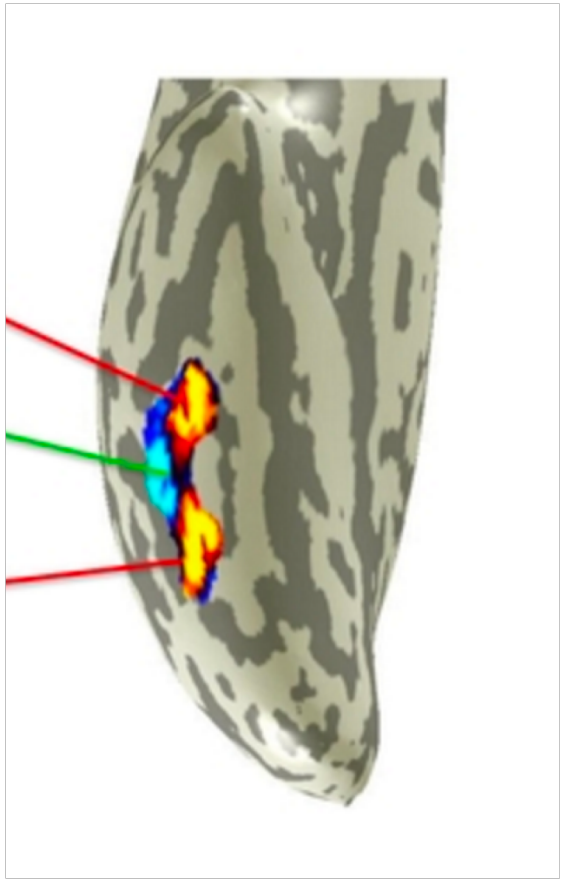
The same subjects (N = 14) participated in an fMRI blocked experiment



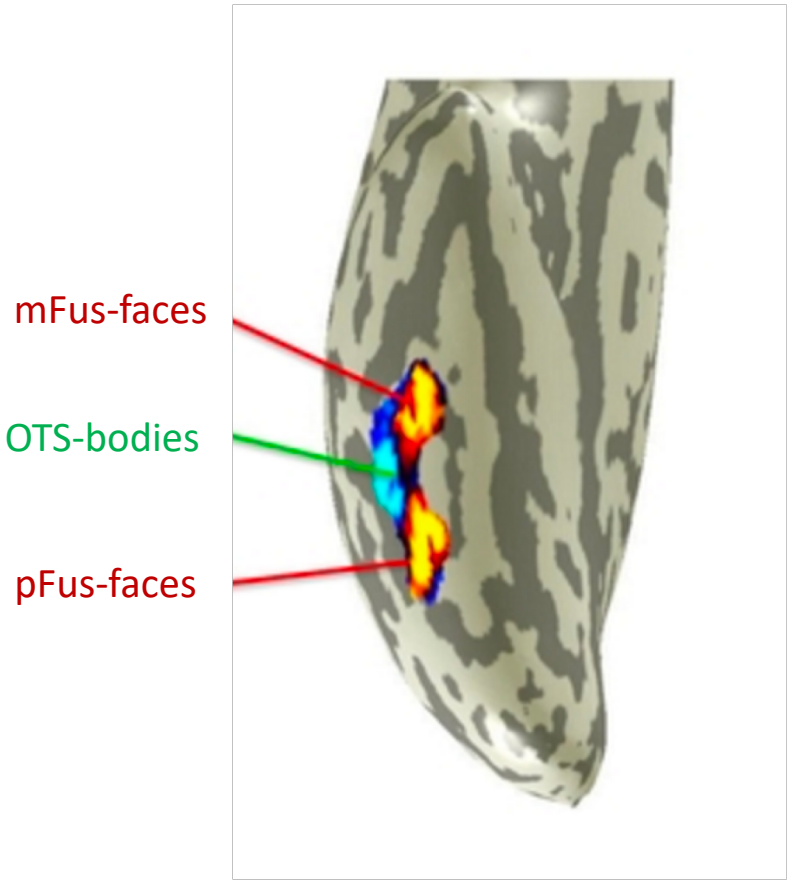


- 1-back task with fixation, indicating when two images are the same
- morph levels were pseudorandomized
- 4 runs, 126 time points each
- 2.4 mm isovoxel

We first localized face- and body-selective regions in VTC in each subject using an independent localizer



We first localized face- and body-selective regions in VTC in each subject using an independent localizer, and then extracted responses to the morphed stimuli from each region

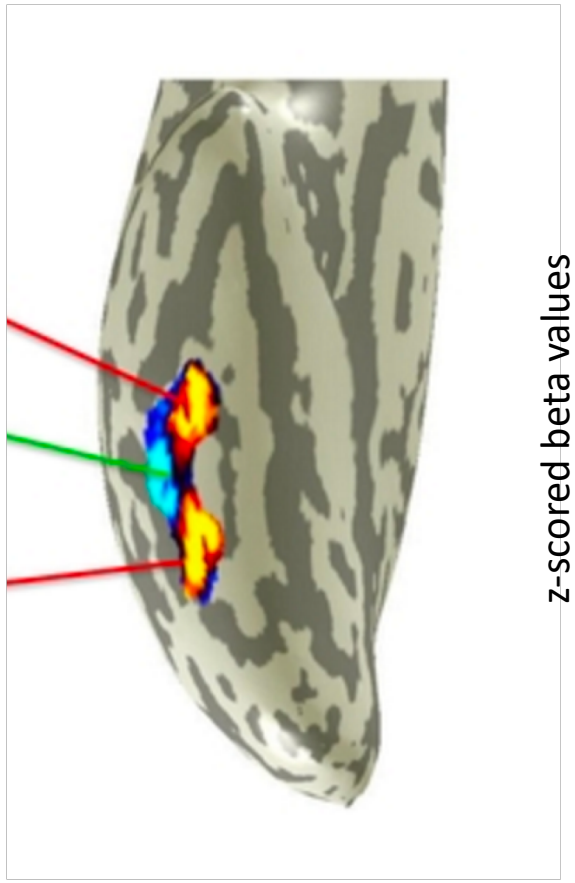


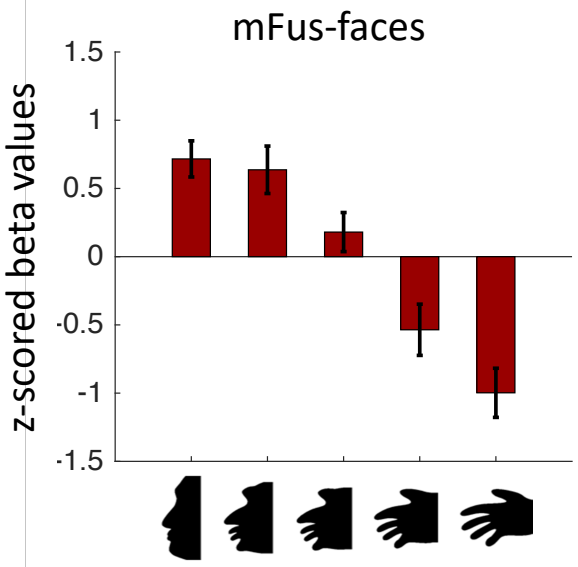
mFus-faces responds similarly to morphs 1,2 which are categorized as faces, then responses gradually decrease

mFus-faces

OTS-bodies

pFus-faces



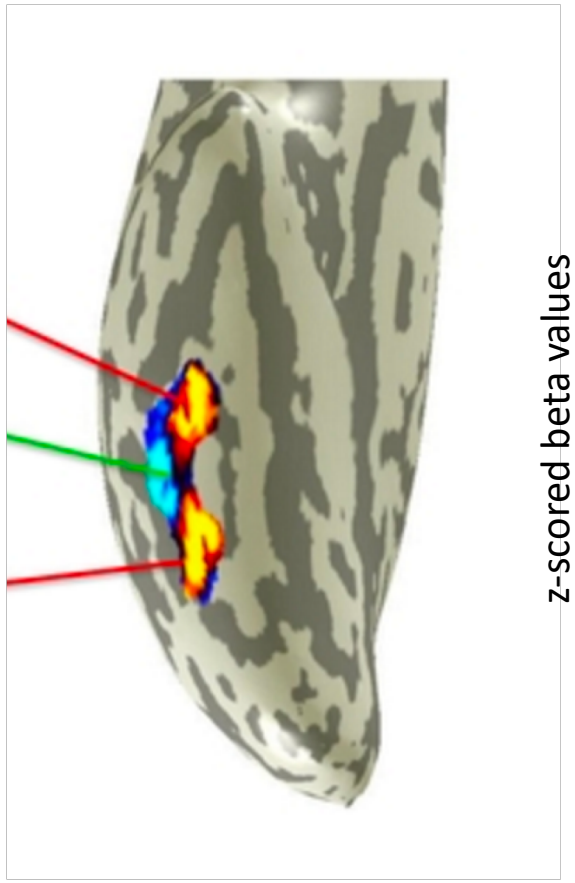


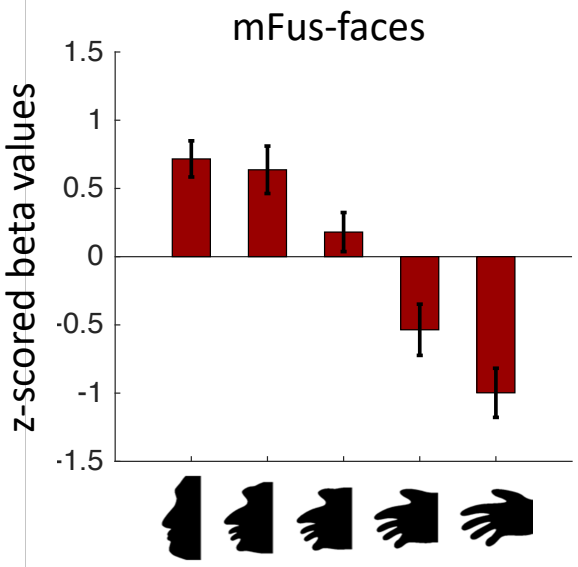
pFus shows a similar pattern

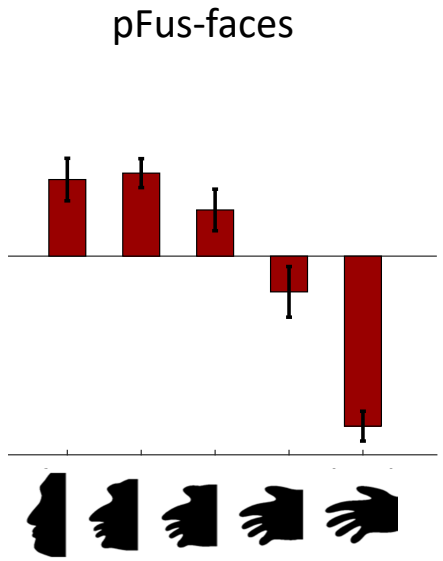
mFus-faces

OTS-bodies

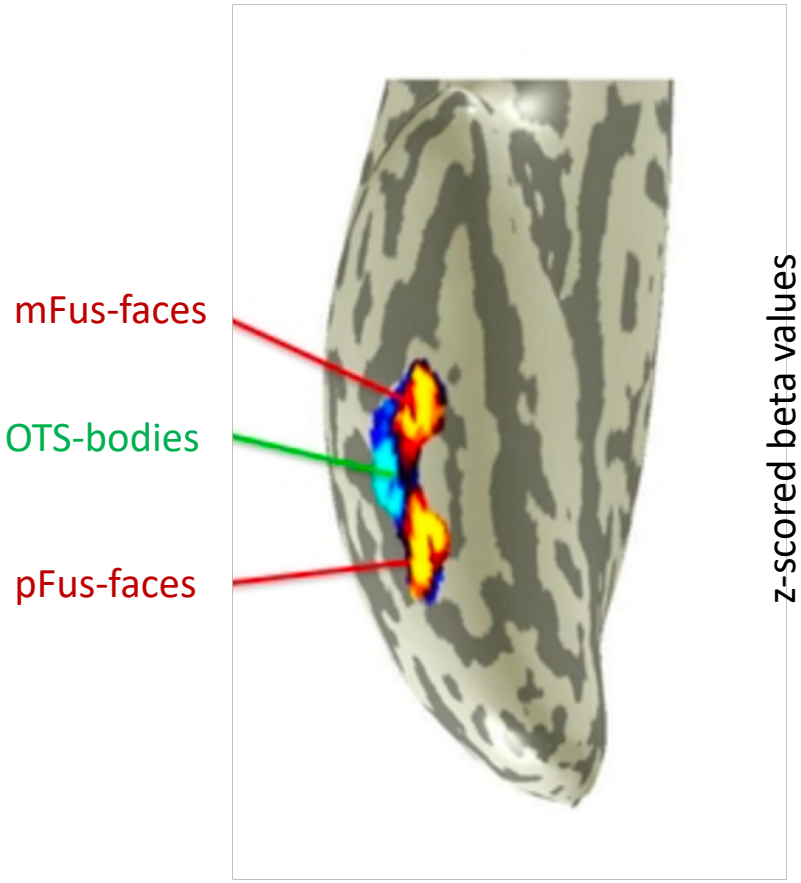
pFus-faces

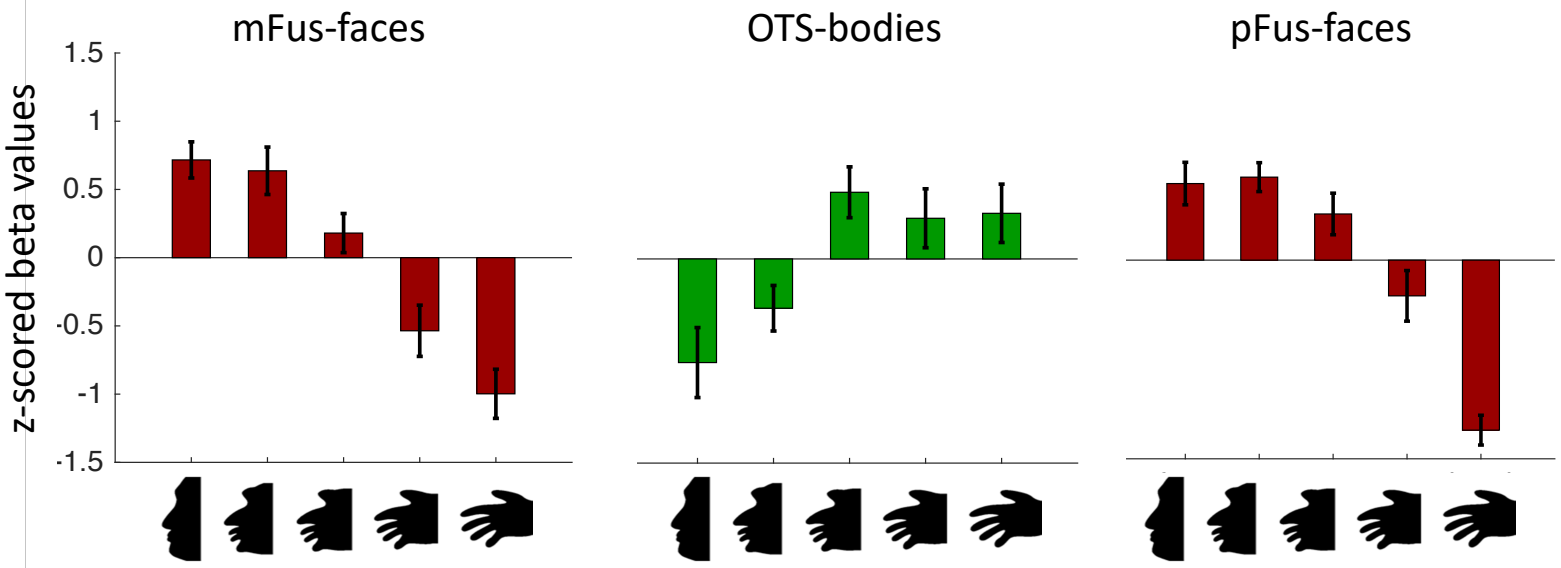






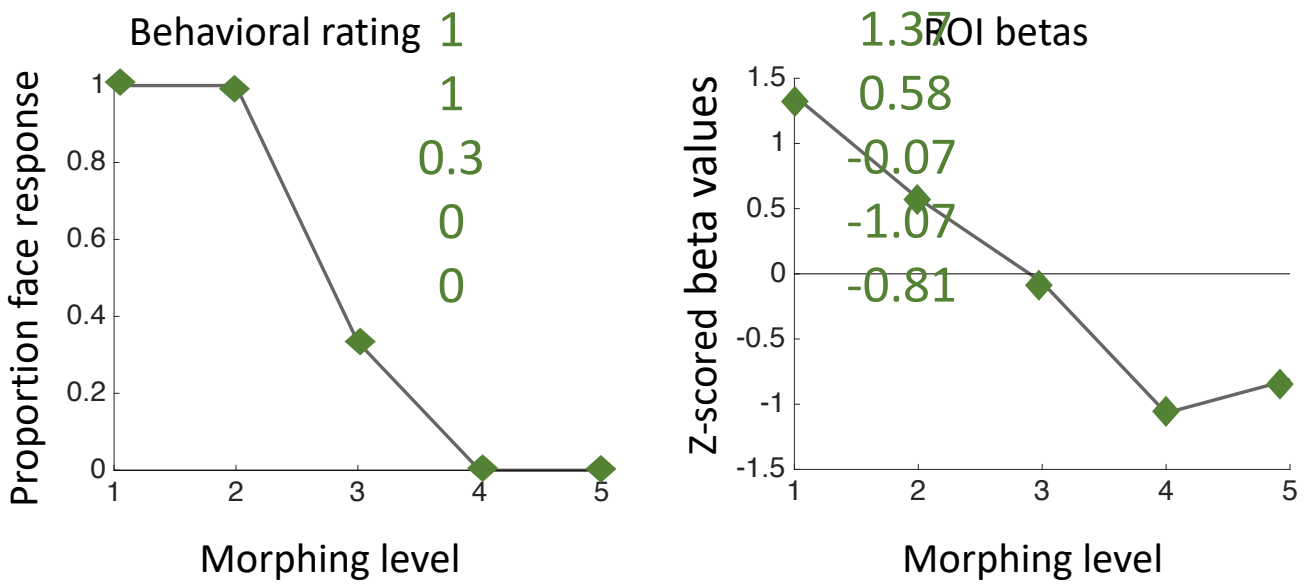
In contrast, OTS-bodies responds similarly to morphs 3-5, and gradually less to morphs 1,2



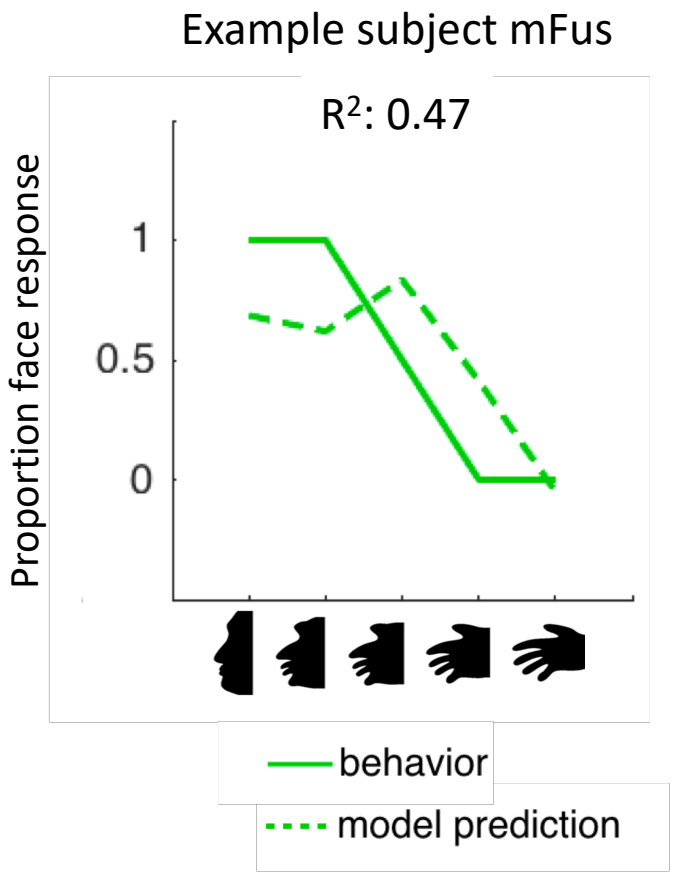


Does perceptual categorization correlate with neural responses in mFus-faces, pFus-faces and OTS-bodies?

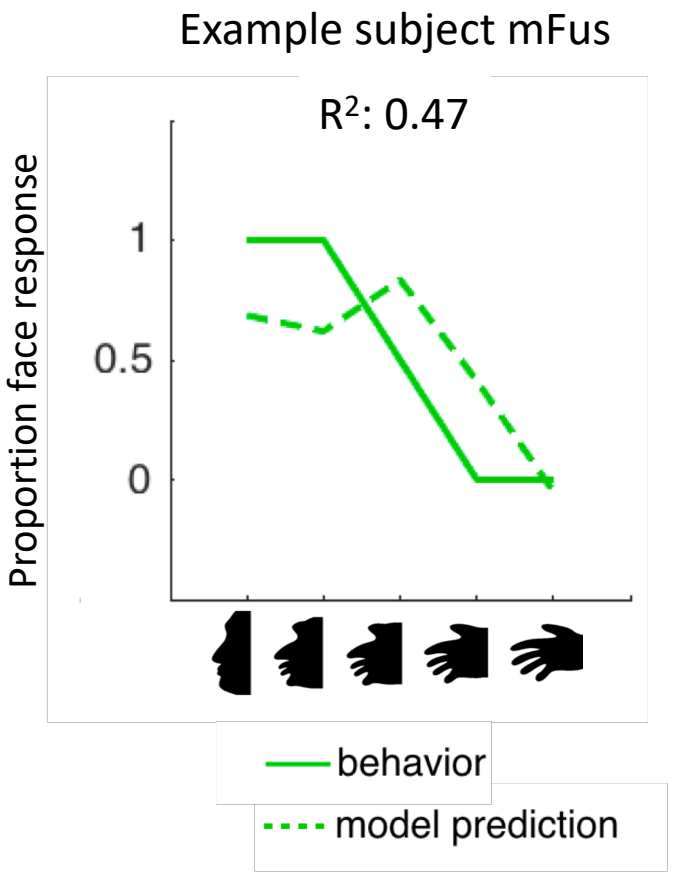
$$y = \alpha + \beta x$$

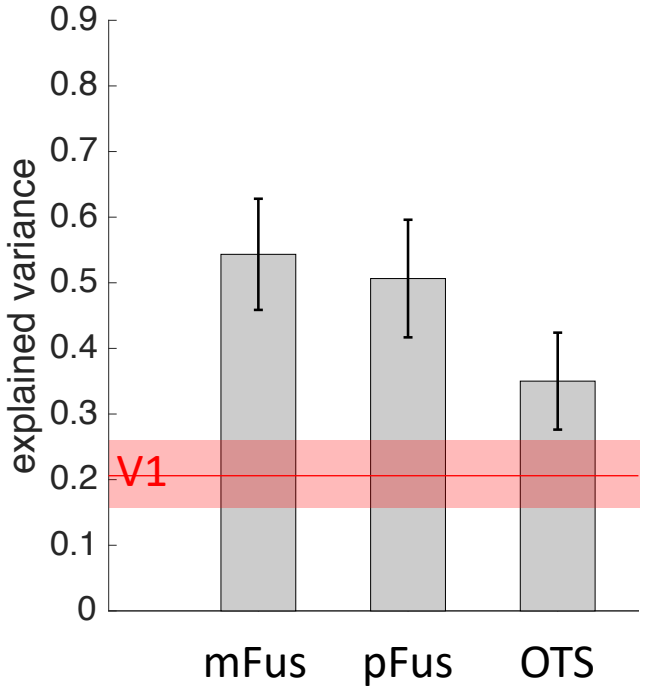


Example subject's mFus-faces data in relation to their behavioral categorization task



mFus-faces, pFus-faces and OTS-bodies are significantly higher correlated to behavioral categorization than control area V1





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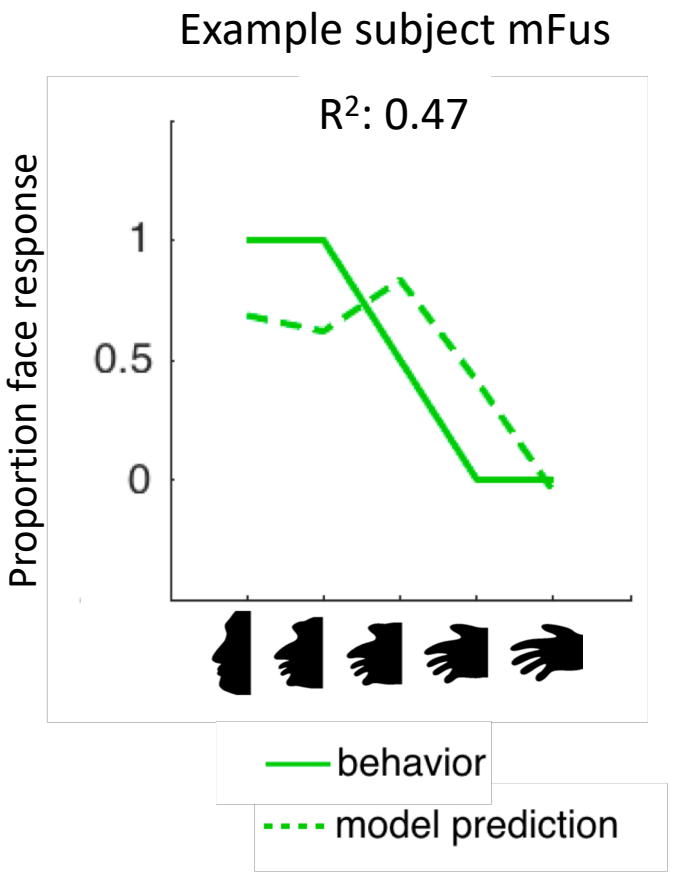
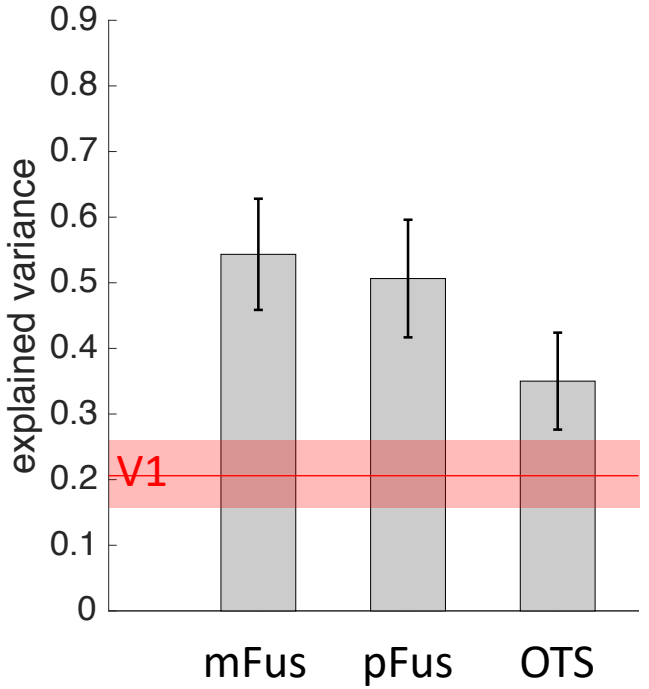
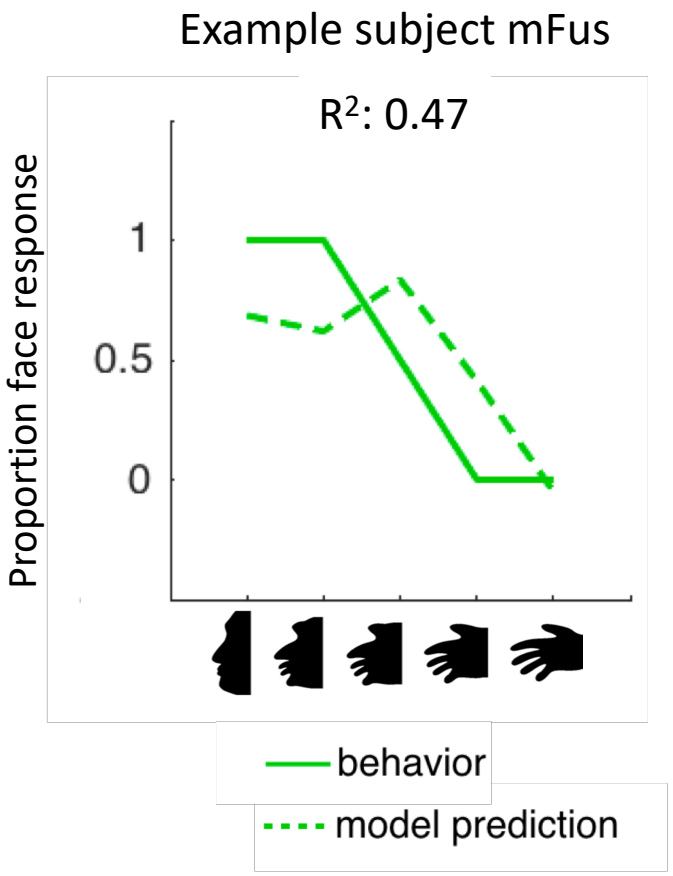
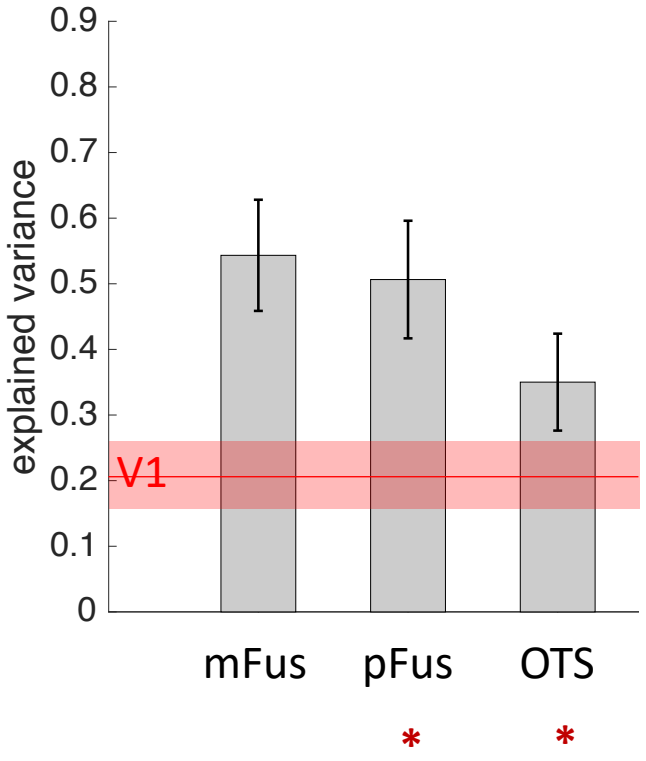




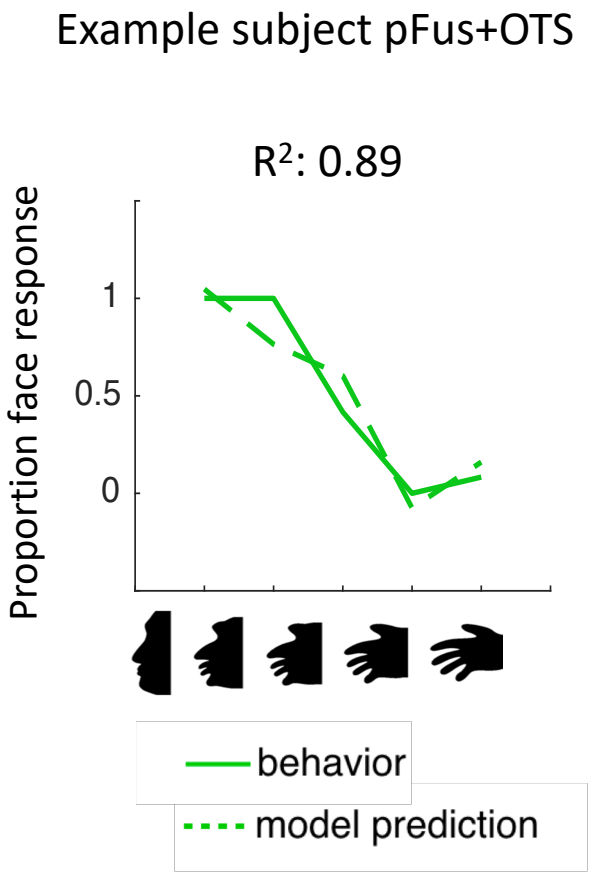
Stepwise linear regression

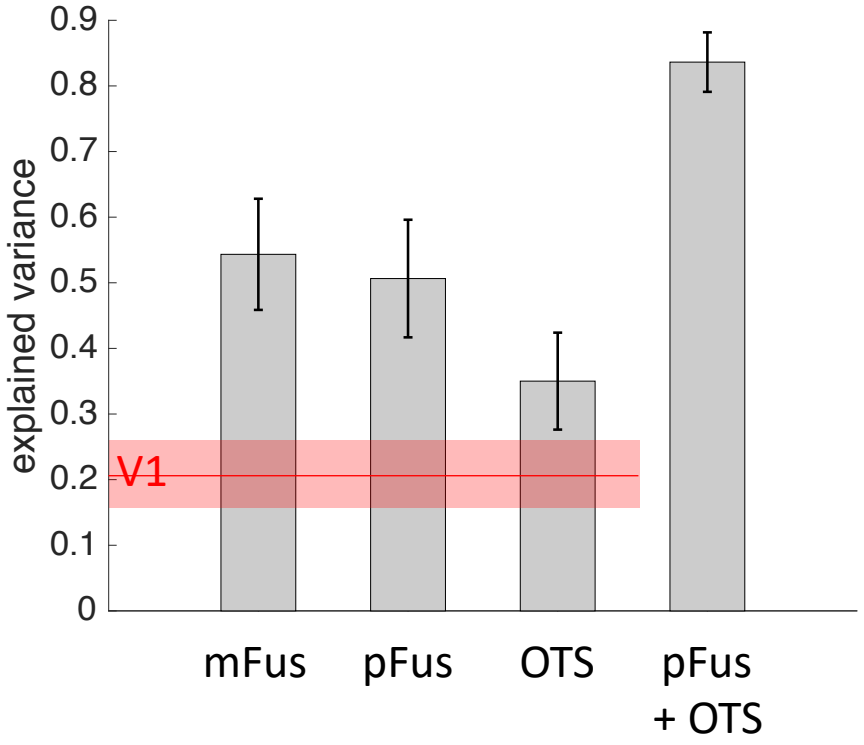
Stepwise linear regression indicates that both pFus and OTS are significant predictors in explaining behavioral categorization





A linear model using pFus and OTS as predictors explains on average 82% of the variance of behavioral categorization





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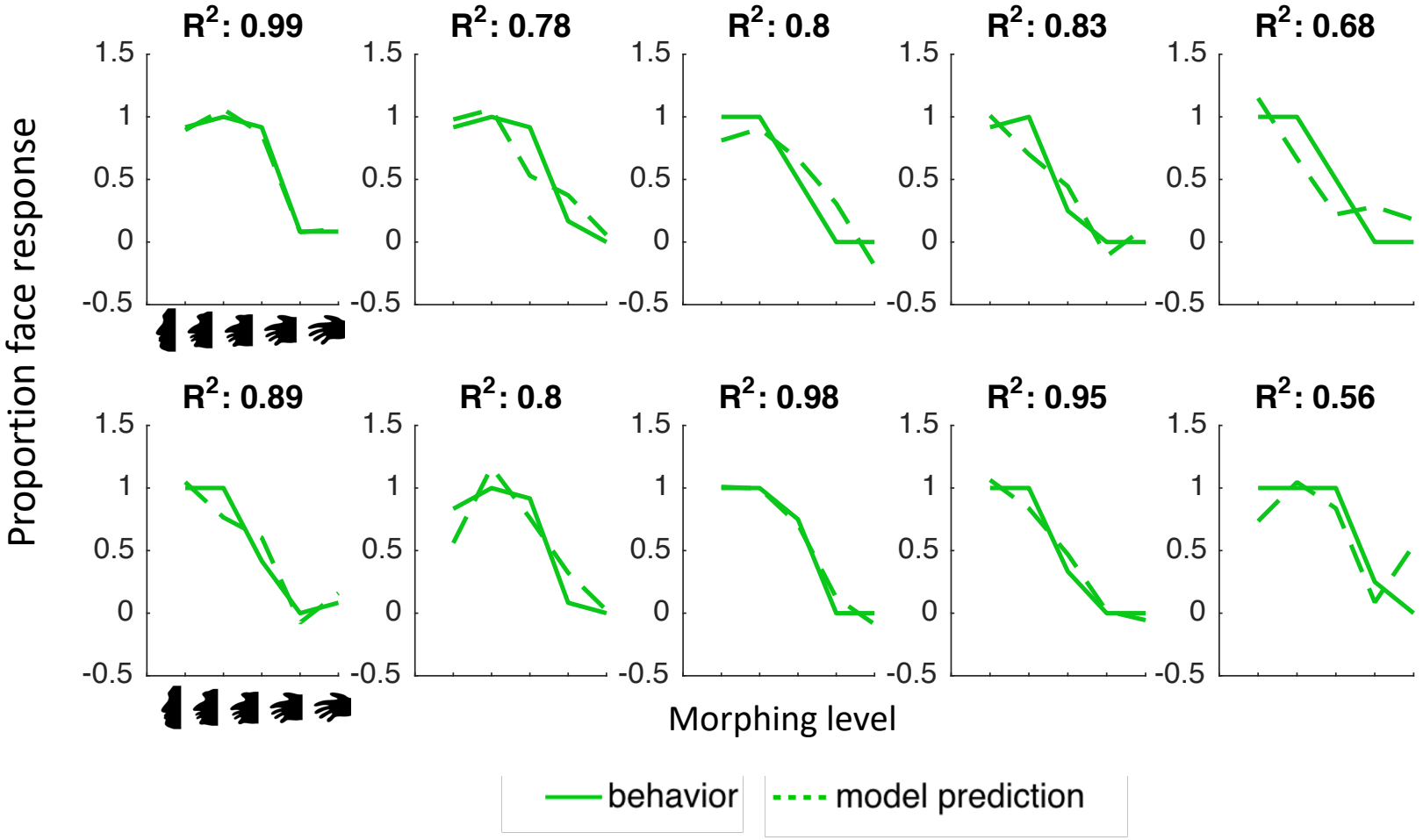
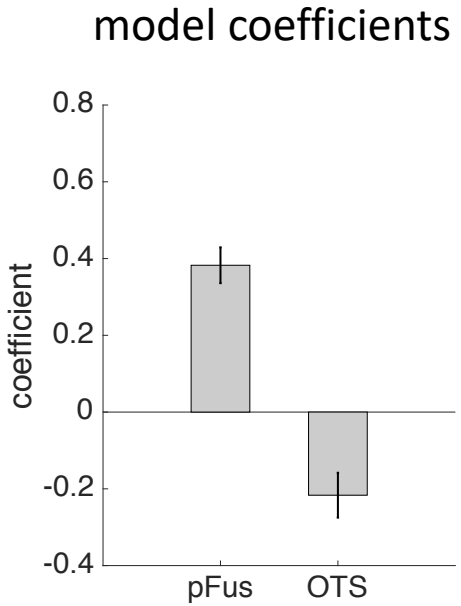
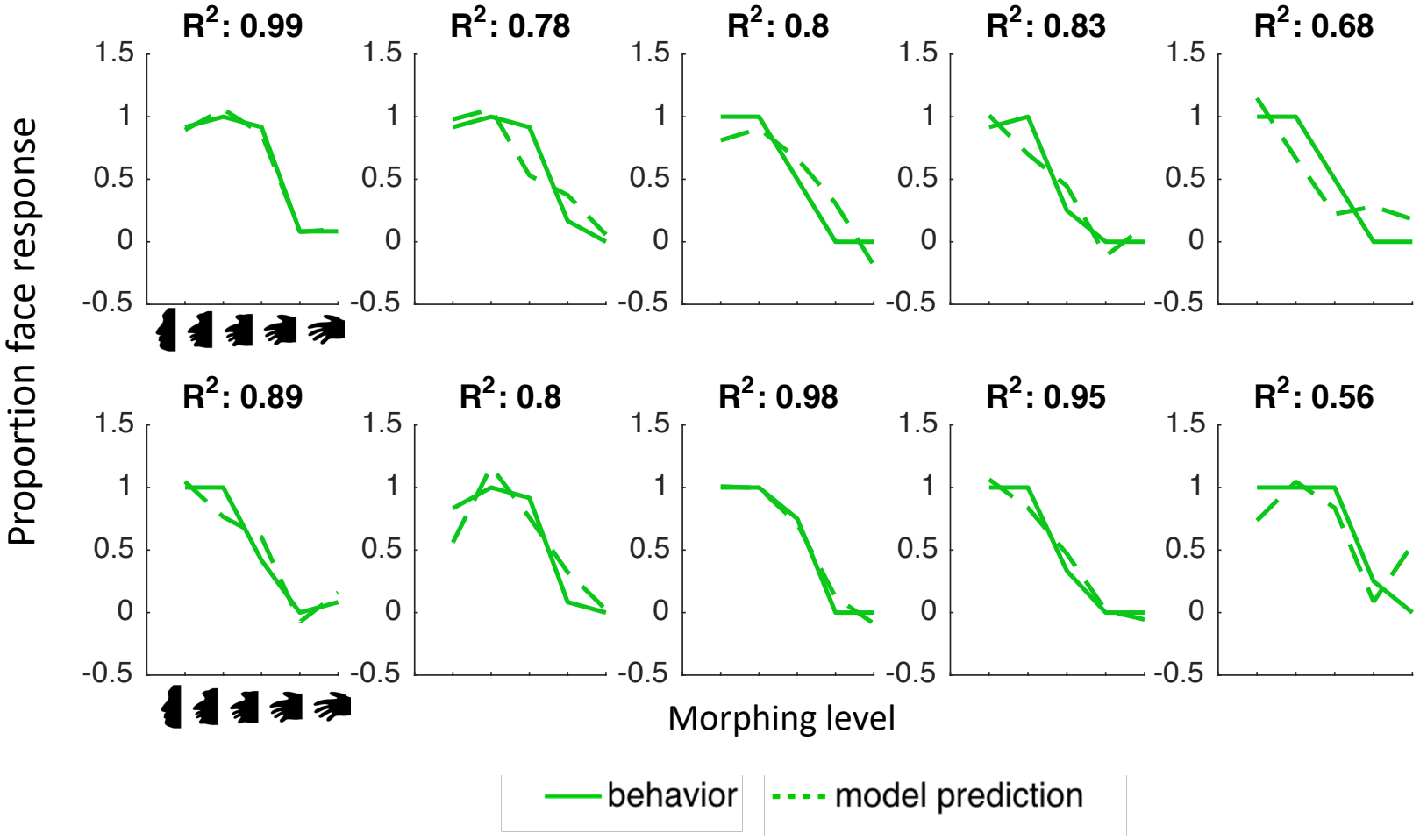
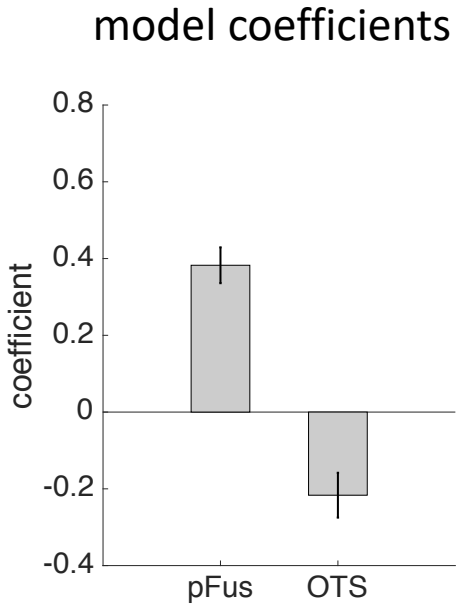


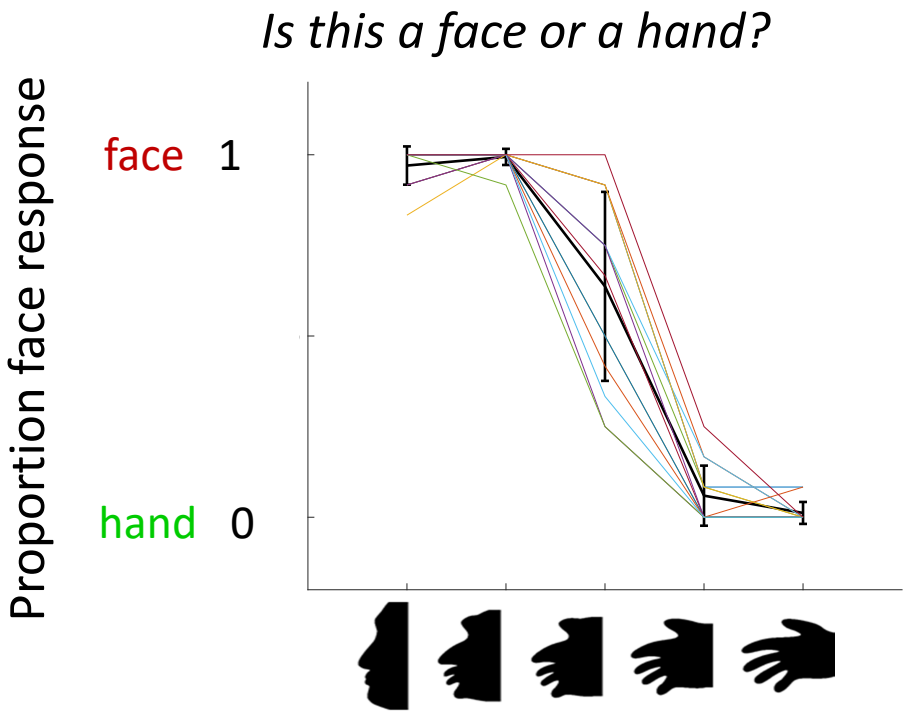


We can best explain categorization behavior in each subject by taking the relative contribution of pFus-faces and OTS-bodies.





Can we build a general model?



Can we build a general model to predict your behavioral categorization response?

Training model on N-1 subjects

$$y = \alpha + \beta_1 x_1 + \beta_2 x_2$$

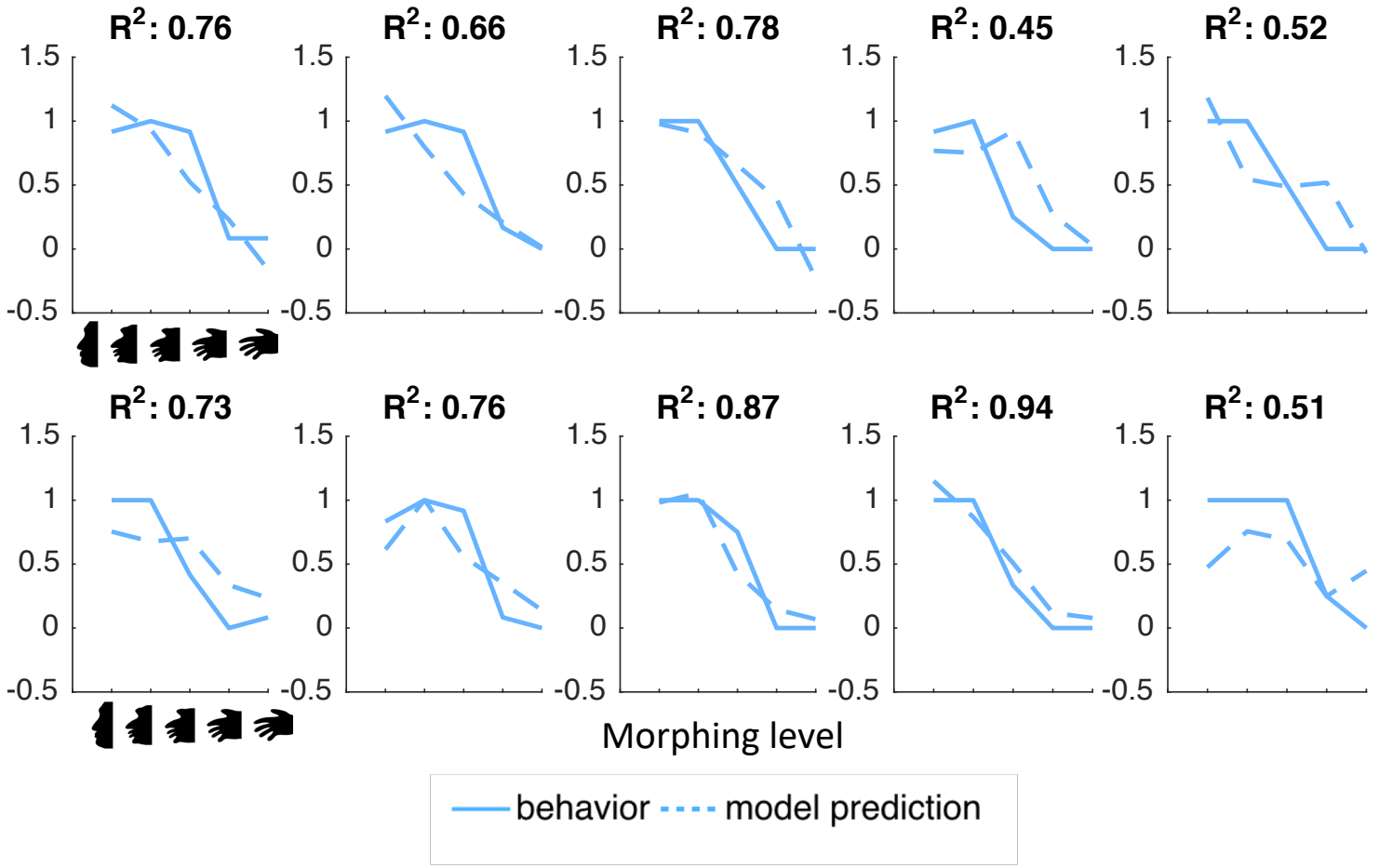
subject 1 **behavior**	subject 1 **pFus** betas	subject 1 **OTS** betas
subject 2 **behavior**	subject 2 **pFus** betas	subject 2 **OTS** betas
...	...	...
subject N-1 **behavior**	subject N-1 **pFus** betas	subject N-1 **OTS** betas

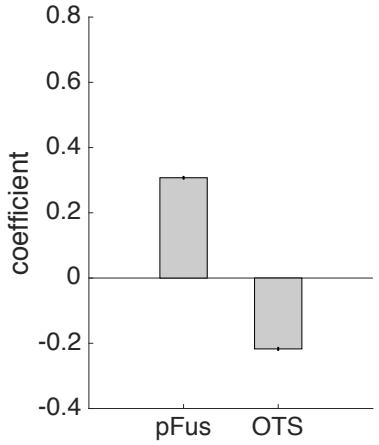
α, β_1, β_2

Testing on Nth subject

subject N behavior = α + β_1 . subject N **pFus** betas + β_2 subject N **OTS** betas

We can build a model that predicts perceptual categorization in new subjects from their brain responses;
Model explains 70% of the variance in new subjects





Conclusion

(1) Perceptual categorization of ambiguous face-hand stimuli is better predicted by differential responses across a face and a body region than responses of each of these regions separately.

(2) These differential responses explain ~82% variance of perceptual categorization in individual subjects

(3) Elucidating the relationship between brain activity and perceptual categorization in individual subjects enabled us to build a general model that predicts ~70% of the variance of perceptual categorization in new subjects, solely based on their neural data

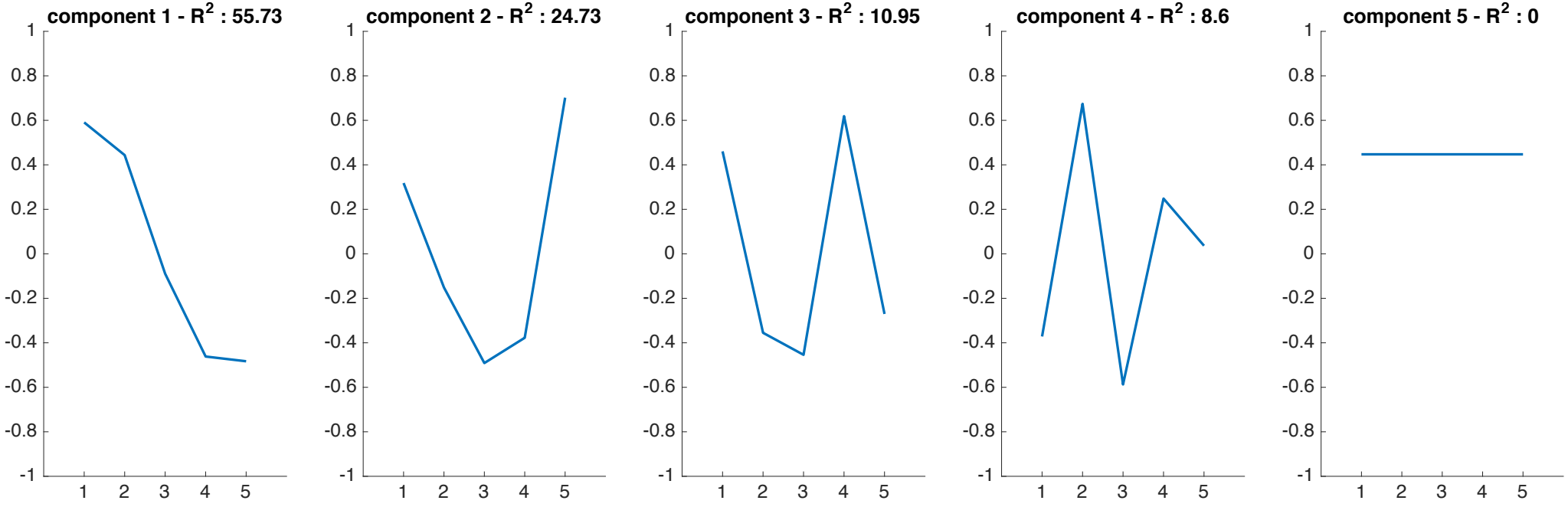
Thank you!

Kalanit Grill-Spector

Kevin S. Weiner

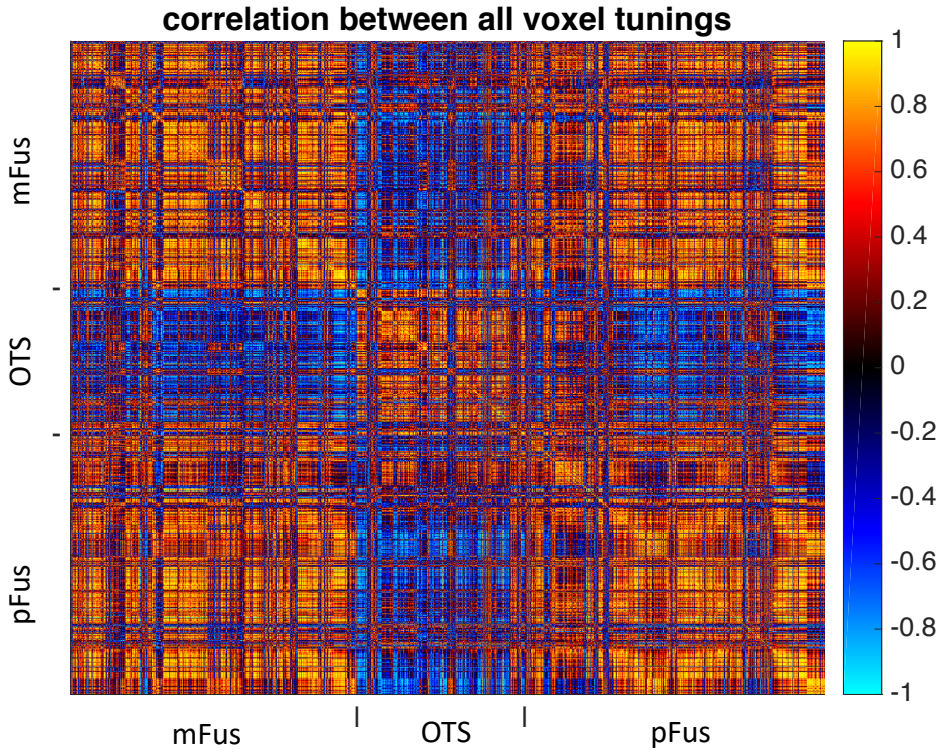
Nicolas Davidenko

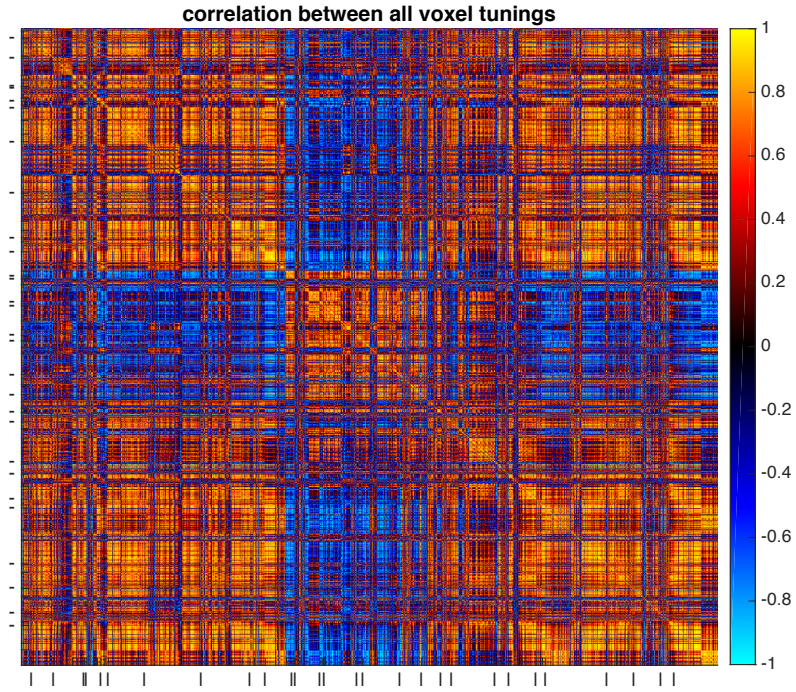
PCA results



81 % variance explained by first two components

Correlation across voxel tunings of mFus, OTS, pFus





Same matrix as on the left, but subjects are marked on axes

=> There is variability in tuning functions within an ROI and variability across subjects, but the dominant difference is between face and body selective-region's tuning curves