Attentional allocation locally warps neural representational space

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Introduction

Selective attention is a computational mechanism by which the brain prioritizes certain types of information. Electrophysiological work suggests that attention alters neuronal tuning across populations[1] and increases interneuronal decorrelation[2]; however, these mechanisms have been characterized using rudimentary visual stimuli. Here we examine how attention reshapes complex, high-dimensional representations grounded in distributed neuronal populations.

Hypothesis: Attentional allocation transiently and selectively warps high-dimensional neural representational space such that task-relevant representations become more discriminable, while task-irrelevant representations are collapsed.

Methods

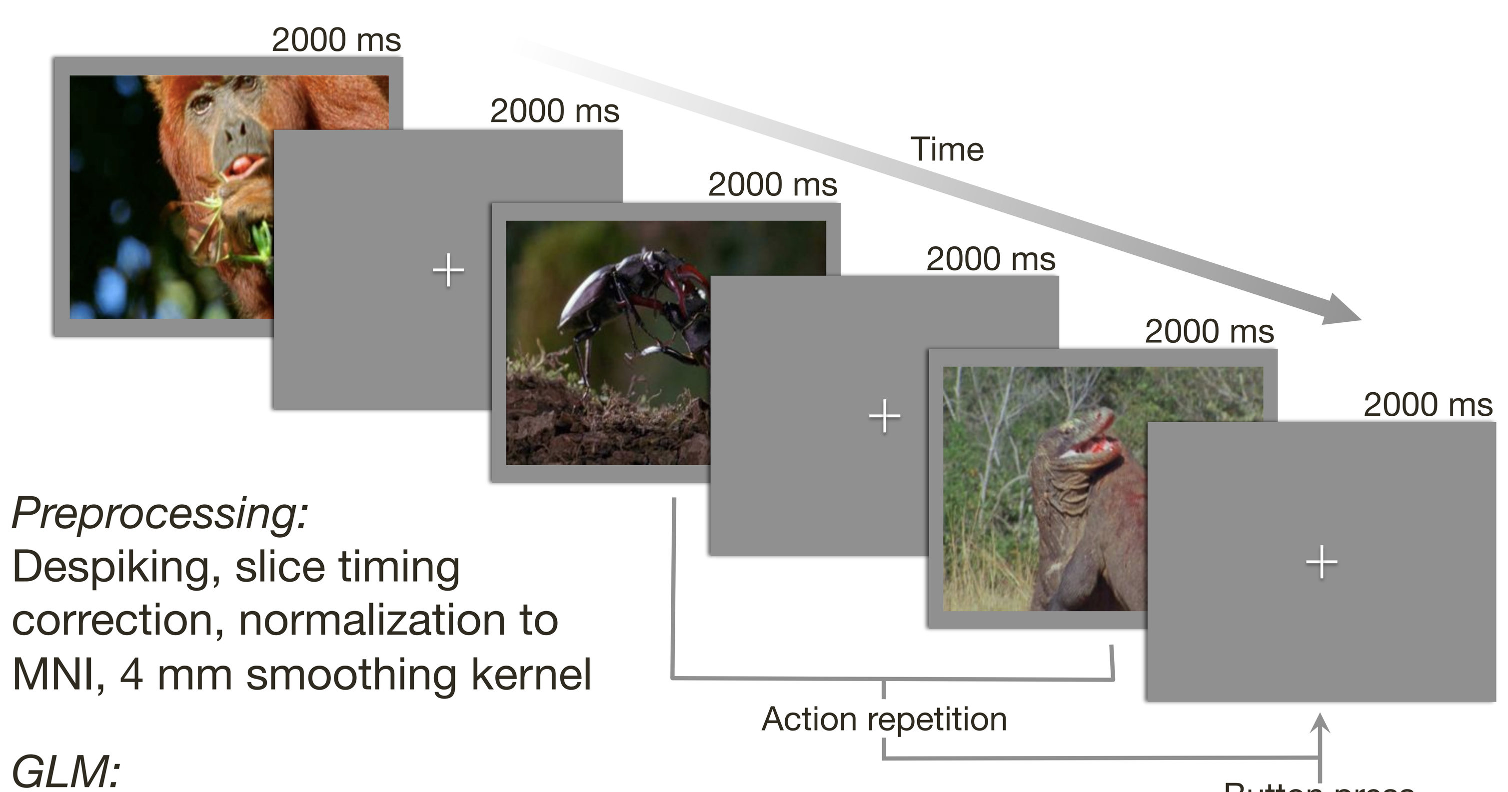
12 right-handed participants (7 female)

Stimuli: 2000 ms naturalistic video clips of animals performing actions

Rapid event-related design: 2000 ms stimulus + 2000 ms fixation

5 animal types: birds, insects, primates, reptiles, ungulates
4 action types: eating, fighting, running, swimming
20 conditions: 5 (animal type) x 4 (action type) fully crossed design

Attentional task: 1-back repetition detection requiring participants attend to either animal type or action type



Preprocessing:
Despiking, slice timing correction, normalization to MNI, 4 mm smoothing kernel

GLM:
Runwise GLM using canonical HRF

Repetitions/button presses, motion parameters included as nuisance regressors

Two methods of multivariate information mapping to localize attentional warping effects:
- Representational similarity regression
- Linear SVM classification with samplewise cross-validation

Implemented using 100-node surface-based searchlights[3]

Hyperalignment:
Whole-brain time series hyperalignment using 200-node surface-based searchlights[4]

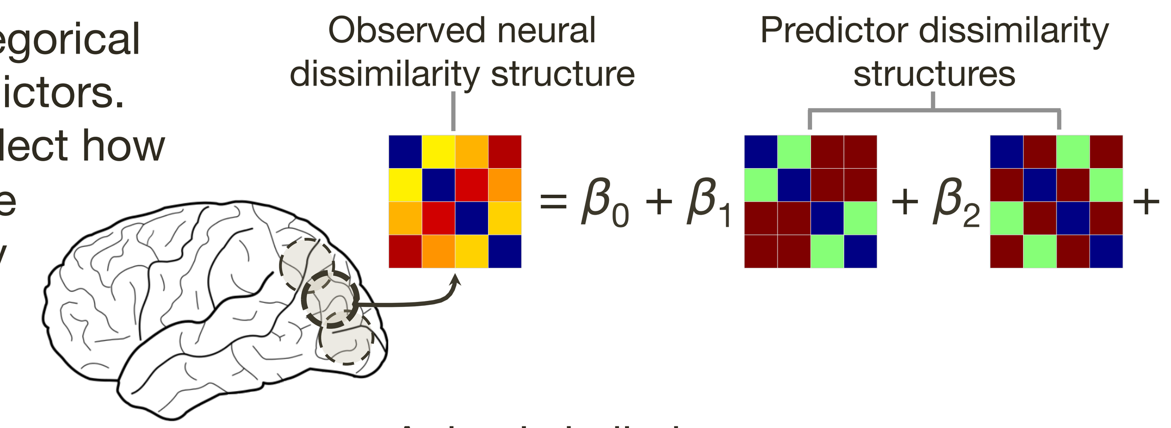
19 participants (including 12 participants from first session)

1 hr freely viewed naturalistic movie (*Life* nature documentary, narrated by David Attenborough)

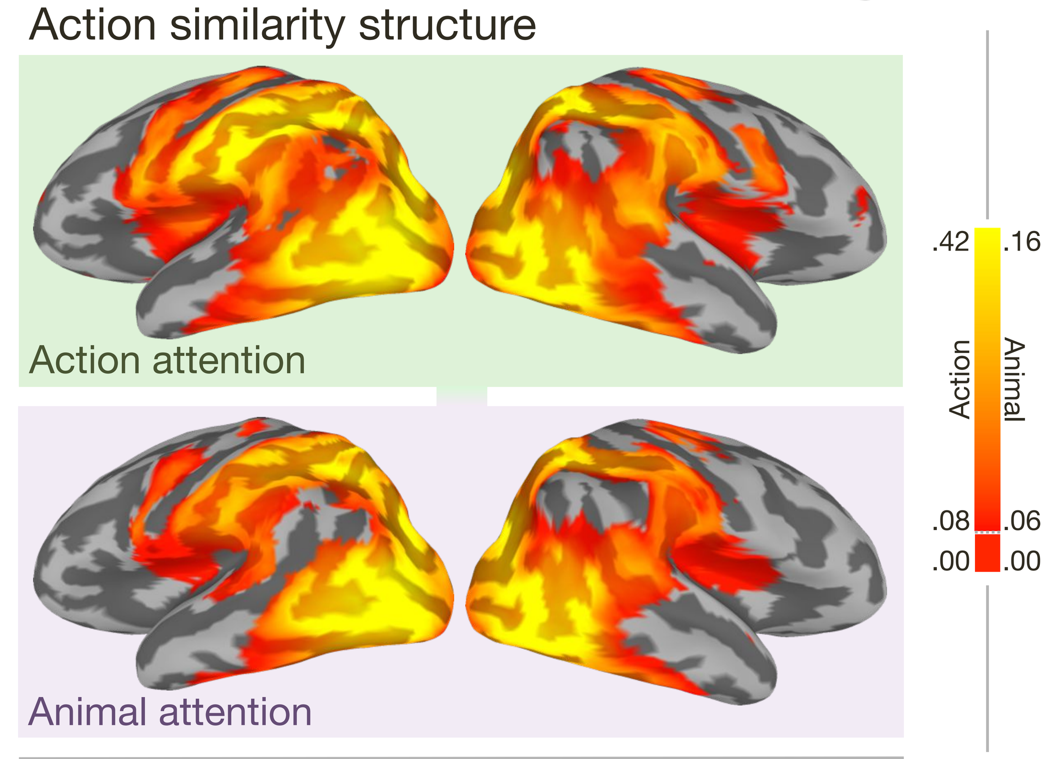
All analyses performed on hyperaligned experimental data

Representational similarity regression searchlight

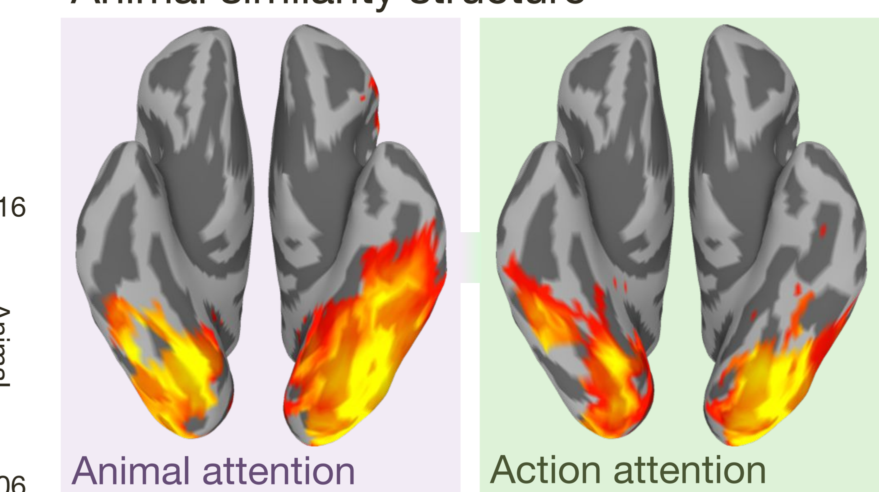
Multiple regression using two categorical target similarity structures as predictors. Regression coefficients (β_1, β_2) reflect how well each target similarity structure predicts observed neural similarity structure.



Action similarity structure

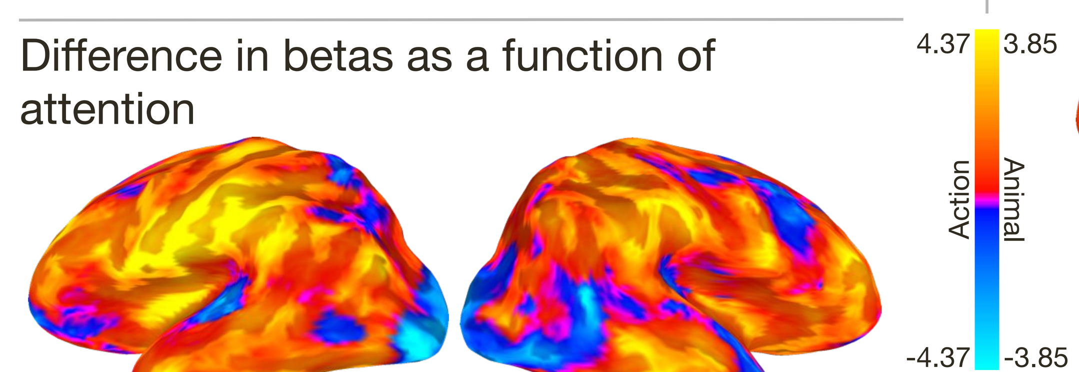


Animal similarity structure



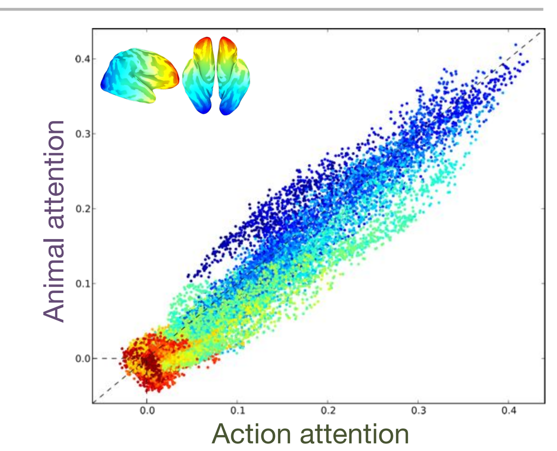
Mean regression coefficient (beta) thresholded at $t(11) = 3.11$, $p < .005$, uncorrected

Difference in betas as a function of attention

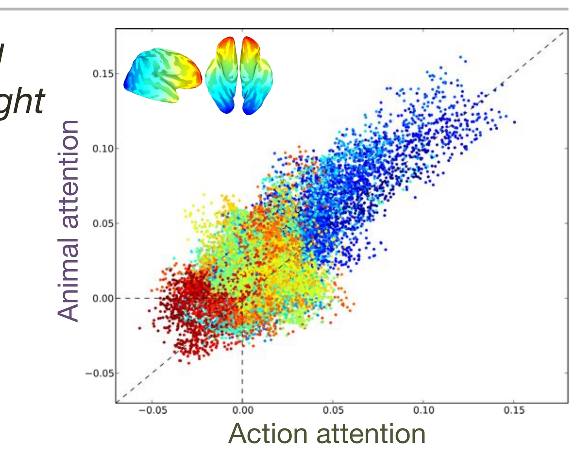


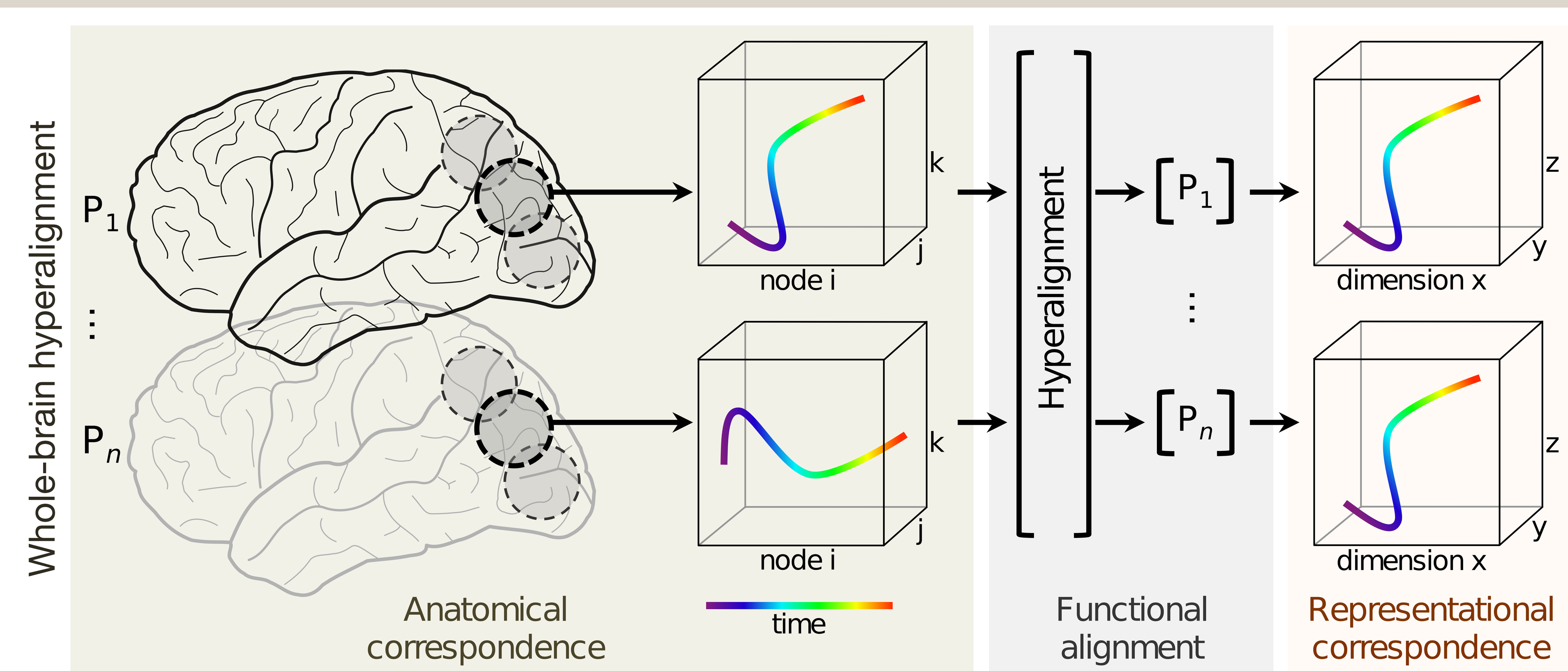
Z-transformed searchlight t-statistic for paired t-test, unthresholded, uncorrected

Change in action beta per searchlight as a function of attention



Change in animal beta per searchlight as a function of attention

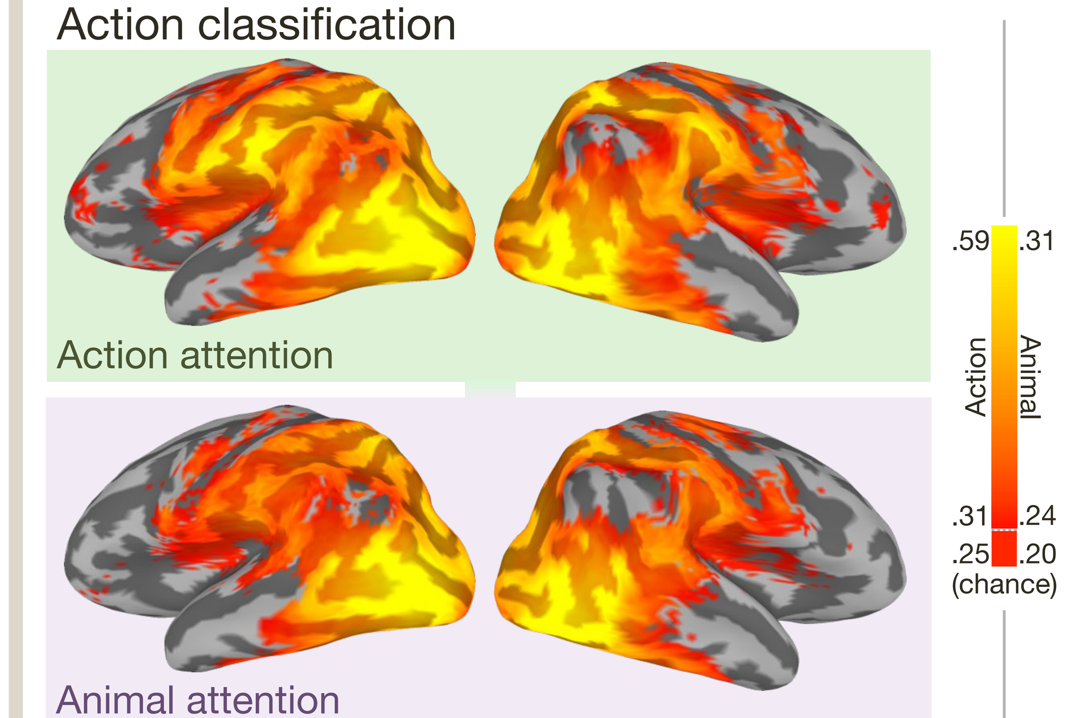




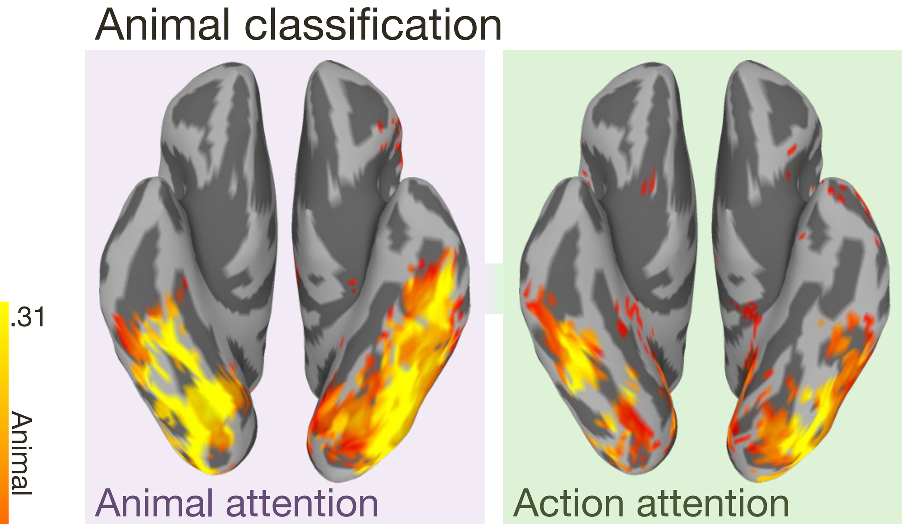
Linear SVM classification searchlight

Surface-based searchlight classification using leave-one-sample-out cross-validation to control for low-level visual similarity.

Action classification

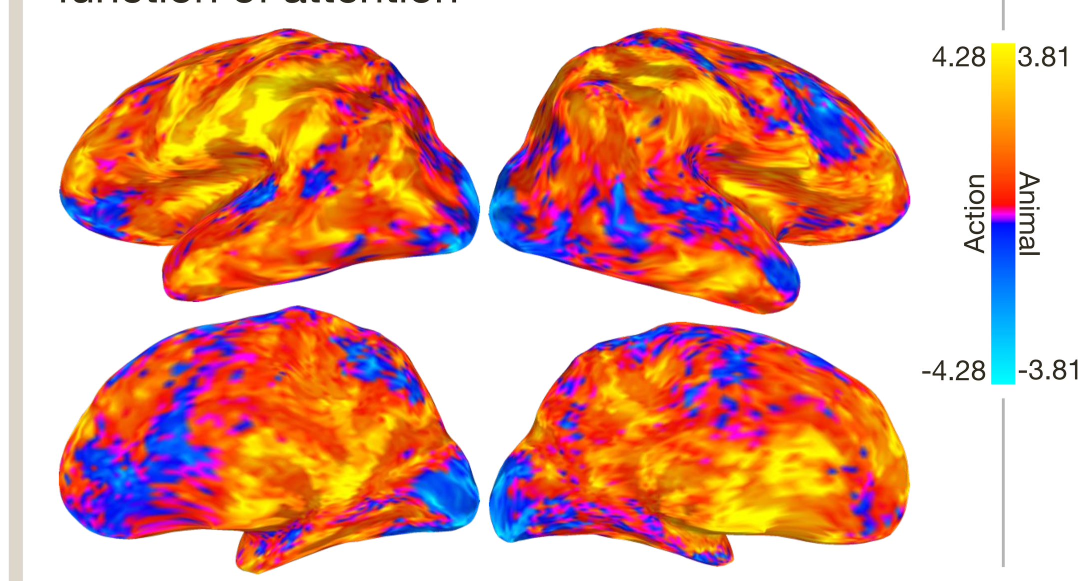


Animal classification

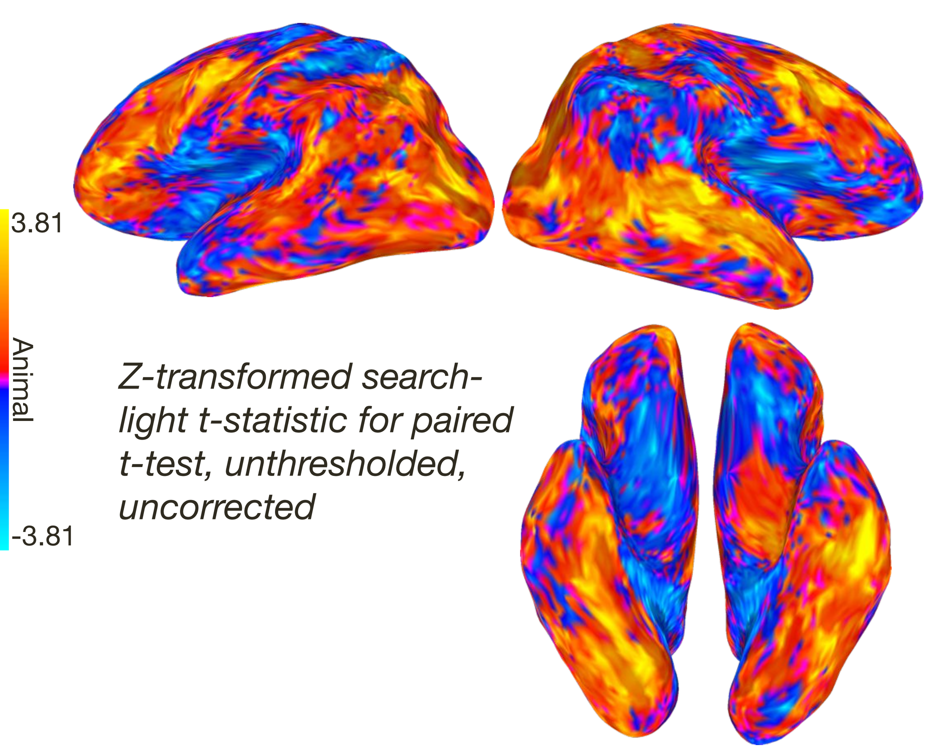


Mean searchlight classification accuracy thresholded at $t(11) = 3.11$, $p < .005$, uncorrected

Difference in classification accuracy as a function of attention



Z-transformed searchlight t-statistic for paired t-test, unthresholded, uncorrected



Conclusions

Representational similarity regression and linear SVM classification yielded convergent searchlight results.

Robust action representation was found in lateral occipitotemporal cortex, posterior parietal, pre- and postcentral gyri. Animal representation was greatest in lateral occipital, posterior parietal, and ventral temporal cortices.

Attending to actions increased action discriminability in pre- and postcentral gyri and decreased discriminability in early visual cortex. Attending to animals increased animal discriminability in ventral temporal cortex.

Task-based changes in representational structure generalized across participants aligned to a common space via whole-brain hyperalignment.

Attentional warping effects adhere to the functional topography of cortex and are localized to areas representing task-relevant category information.

References:
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2. Cohen, M. R. & Maunsell, J. H. (2009). Attention improves performance primarily by reducing interneuronal correlations. *Nature Neuroscience, 12*(12), 1594-1600.
3. Oosterhof, N. N., Wiggett, A. J., Diedrichsen, J., Tipper, S. P., & Downing, P. E. (2010). Surface-based information mapping reveals cross-modal vision–action representations in human parietal and occipitotemporal cortex. *Journal of Neurophysiology, 104*(2), 1077-1089.
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