Attention to Action Categories Shifts Semantic Tuning Toward Targets Across the Brain

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Abstract Submission

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Introduction:

Humans are remarkably adept in social interactions in the real world, an ability that requires reliable detection of visual objects along with their various actions [4]. A previous study from our laboratory shows that object-based attention causes broad shifts in voxel-wise semantic tuning toward the target [2]. This is consistent with the view that the visual system implements a "matched filter" to optimize the processing of behaviorally-relevant objects during natural vision [3]. Recent reports suggest that not only objects but also hundreds of action categories are represented via a continuous semantic space [5]. However, little is known about representational modulations during action-based attention. Here, we sought to assess semantic representations during natural visual search for action categories.

Methods:

Five human subjects viewed 30 min of natural movies while performing two separate attention tasks: search for animate targets that perform "communication" or search for animate targets that perform "locomotion". The two tasks were interleaved and performed in separate 10 min runs. Whole-brain BOLD responses were recorded using fMRI. Responses were detrended using a Savitzky-Golay filter. To remove baseline or gain modulations, voxel-wise responses were z-scored to attain zero mean and unity variance. A stimulus matrix was constructed by labeling the presence of 813 object and 109 action categories in the movies. Object-driven responses were regressed out of measured BOLD responses in single voxels. Separate voxel-wise action-category models were then fit under each attention task [5]. To estimate the semantic space underlying action-category representation, principal components analysis was performed on voxel-wise category models fit during a separate passive-viewing task. Two template tuning profiles were constructed by identifying the set of actions that belong to each of the two target categories. Voxel-wise tuning profiles and template tuning profiles were projected onto the semantic space. Tuning strength for each target was then quantified as Pearson's correlation coefficient between projections of voxel tuning and the target templates. Finally, a tuning shift index (TSI) was quantified using the measured tuning strengths for each voxel. Tuning shifts toward/away from the attended category will yield positive/negative TSIs in the range [-1, 1].

Results:

We find that attention to action categories causes tuning shifts toward the target category in many cortical voxels. Tuning shifts are moderate in temporal cortex, but they are substantial in angular gyrus, frontal cortex (SFG, MFG, and IFG), and cingulate cortex (ACC, PCC; Fig. 1). The average TSI is 0.064±0.011 in angular gyrus, 0.026±0.006 in frontal cortex, and 0.015±0.005 in cingulate cortex (mean±s.e.m, across all five subjects). TSI was not significant in temporal cortex (STG, MTG, pSTS), and in supramarginal gyrus (bootstrap test, $p>0.05$; Fig. 2). Overall, TSI is substantially high in higher areas of the action observation network (AON) [1] and in more anterior cortical areas belonging to the attention network ($p<0.05$).

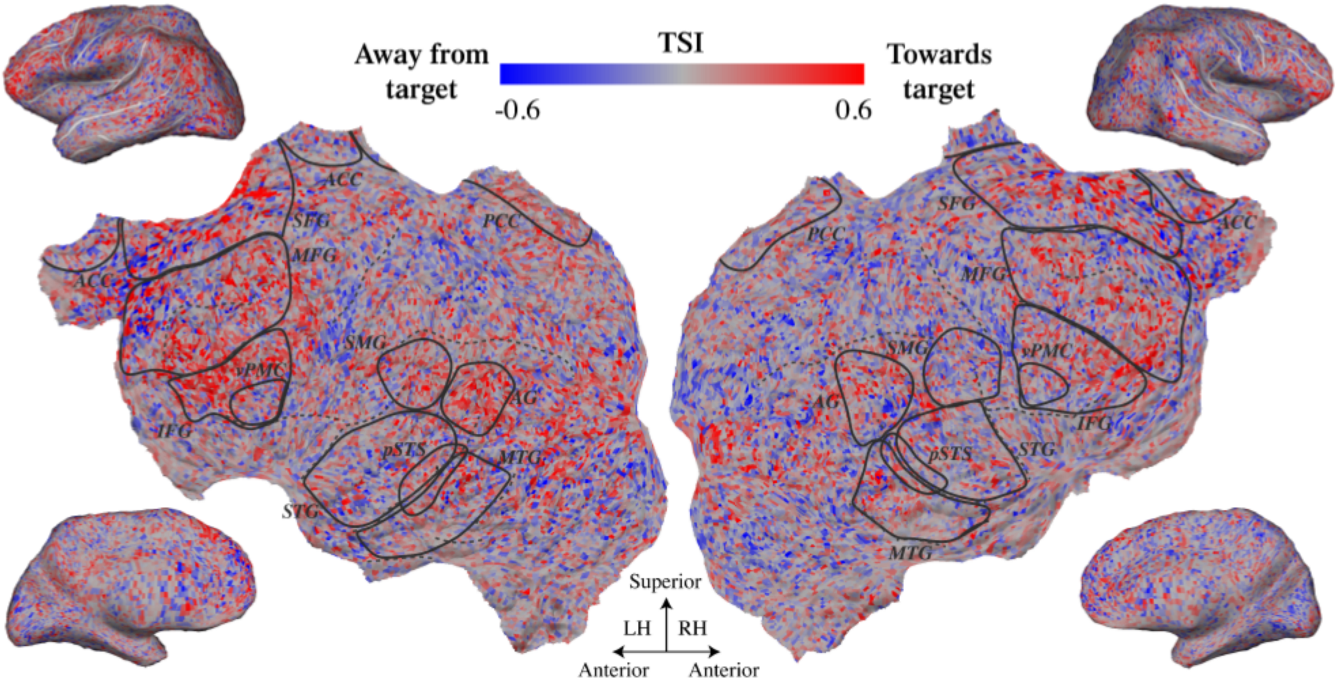

Figure 1: Attention to action categories causes tuning shifts in single voxels. To assess attentional changes of the semantic tuning, we projected voxel-wise tuning profiles onto a continuous semantic space. The semantic space was derived from principal components analysis (PCA) of tuning profiles measured during a separate passive-viewing task. The idealized tuning profiles corresponding to each of the target categories were also projected onto the semantic space. The projected tuning profiles were compared to the projected idealized tuning profiles and a tuning shift index (TSI) was quantified to measure the amount of shift in tuning of a voxel toward targets. The TSIs for a representative subject are shown on a cortical flat map. The color bar represents the 95% central range of TSIs. Anatomical regions of interest are indicated by solid lines: SFG, superior frontal gyrus; MFG, middle frontal gyrus; IFG, inferior frontal gyrus; AG, angular gyrus; SMG, supramarginal gyrus; PCC, posterior cingulate cortex; ACC, anterior cingulate cortex; STG, superior temporal gyrus; MTG, middle temporal gyrus; pSTS, posterior superior temporal sulcus; vPMC, ventral premotor cortex. Voxels in many brain regions shift their tuning toward the attended category. Tuning shifts are most prominent in frontal cortex and angular gyrus.

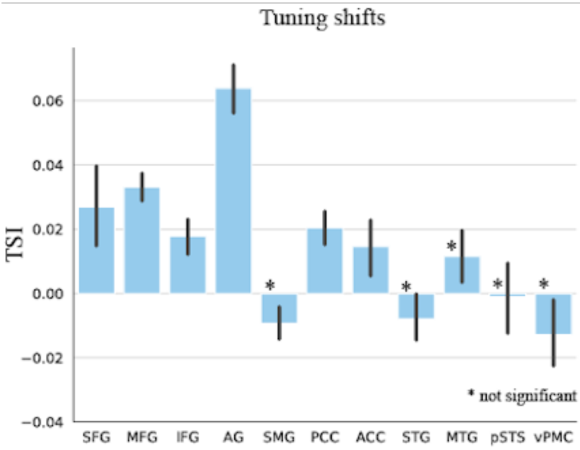

Figure 2: Attention causes various degrees of tuning shifts across ROIs. Tuning shifts are shown across 11 common ROIs assumed to be involved in action representation (mean ± s.e.m across all five subjects). SFG, superior frontal gyrus; MFG, middle frontal gyrus; IFG, inferior frontal gyrus; AG, angular gyrus; SMG, supramarginal gyrus; PCC, posterior cingulate cortex; ACC, anterior cingulate cortex; STG, superior temporal gyrus; MTG, middle temporal gyrus; pSTS, posterior superior temporal sulcus; vPMC, ventral premotor cortex. Attentional tuning shifts are not significant in supramarginal gyrus, in ventral premotor cortex and in temporal lobe (bootstrap test, $p>0.05$). Tuning shifts are relatively more prominent in angular gyrus, frontal cortex, and cingulate cortex ($p<0.05$).

Conclusions:

Our results demonstrate that brain optimizes search for action categories by shifting semantic tuning of single voxels in higher areas of AON and the attention network toward the targets. This finding implies that action perception in the real world is facilitated by a matched-filter mechanism that dynamically modulates representation according to task demand.

Higher Cognitive Functions:

Higher Cognitive Functions Other

Imaging Methods:

BOLD fMRI

Perception and Attention:

Attention: Visual [1]
Perception: Visual [2]

Keywords:

Computational Neuroscience
FUNCTIONAL MRI
Modeling
Perception
Other - semantic representation; action-based attention; action-observation network

[1|2]Indicates the priority used for review

My abstract is being submitted as a Software Demonstration.

No

Please indicate below if your study was a "resting state" or "task-activation" study.

Task-activation

Healthy subjects only or patients (note that patient studies may also involve healthy subjects):

Healthy subjects

Was any human subjects research approved by the relevant Institutional Review Board or ethics panel? NOTE: Any human subjects studies without IRB approval will be automatically rejected.

Not applicable

Was any animal research approved by the relevant IACUC or other animal research panel? NOTE: Any animal studies without IACUC approval will be automatically rejected.

Not applicable

Please indicate which methods were used in your research:

Functional MRI

For human MRI, what field strength scanner do you use?

3.0T

Which processing packages did you use for your study?

Other, Please list - python

Provide references using author date format

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