Tracking the spatiotemporal neural dynamics of object properties in the human brain

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Abstract:

Real-world size and animacy are two major dimensions of object representation. Here, using representational similarity analysis (RSA), we combined high spatial resolution (fMRI) and high temporal resolution (MEG) brain data with theoretical models of the representational content (i.e. size and animacy). We find that animacy (starting ~ 160 msec) and physical object size (starting ~ 150 msec) are both represented in a shared network of regions, from occipital poles (VO, LO) to deeper ventral (fusiform) and medial-temporal structures (Parahippocampal cortex, PHC). Importantly, we find that the Parahippocampal cortex plays a central role in representing both properties over several hundreds of milliseconds, followed by sustained representations in the lateral occipital (LO), ventral occipital (VO) and fusiform. Early visual cortex (EVC) showed a sustained representation of physical object size but not animacy, starting ~150 msec. Resolving the spatio-temporal dynamics of object properties representation shall place new constraints on the computational architecture of visual cognition.

Keywords: real-world size; animacy; spatio-temporal dynamics; MEG; fMRI

Introduction

While vision feels instantaneous, object representation emerges from a network of cortical regions, which operate across multiple spatial and temporal scales. However, in human, the spatio-temporal dynamics at which brain regions encode object features is still in debate. Here, by combining magnetoencephalography (MEG) and functional magnetic resonance imaging (fMRI) with representational similarity analysis (Kriegeskorte & Kievit 2013, Cichy et al., 2016), we reveal the temporal trajectory of the brain regions involved in processing object properties.

Methods and Results

Fifteen subjects saw 118 images (tagged with their real-world size and animacy) in both MEG and fMRI. (see Cichy et al. 2016). The method used here to generate spatiotemporally-resolved maps of the content, termed content-dependent fusion, can be thought of as an MEG-fMRI similarity based fusion (see Cichy et al, 2016) that is further confined by a constraint on the explained similarity variance between MEG and fMRI (see snapshots of the movie in Fig 1). Starting at ~150 ms after stimulus onset, we see the left early visual cortex (EVC), bilateral PHC, lateral and ventral occipital, the fusiform among others representing real-world size. These regions have been reported before in fMRI studies of real-world size (Konkle & Caramazza, 2013, 2016), but their temporal dynamics with regard to processing size information was unknown. Ten ms later at ~160ms is the onset of animacy, where similarly a large shared network of brain areas represent objects based on their animacy (see e.g Kiani et al., 2007). Animacy reaches its peak at 178ms which is overlapping with the peak time observed for PHC and left IT. The peak for size comes ~20 ms later (at 193 ms), where we see bilateral PHC, right VO, and the left MT are engaged. Then moving fast forward from about 220 to 260 we only see PHC alone representing both size and animacy. At 350ms, possibly due to the ongoing recurrent processes, several regions are coming up again to represent both size and animacy. Finally, at 655ms we see EVC is representing real-world size. Given that 655ms is well after the stimulus offset, this is likely driven by top-down feedback from higher visual areas, because there is no incoming visual signal at this point.

Conclusion

We find that size and animacy are represented in overlapping and distributed network of brain areas with different temporal dynamics. By tagging space with time, our findings demonstrate a new kind of spatio-temporal topography of object processing orchestrated by high-level brain structures, which can guide computational architectures of visual cognition.

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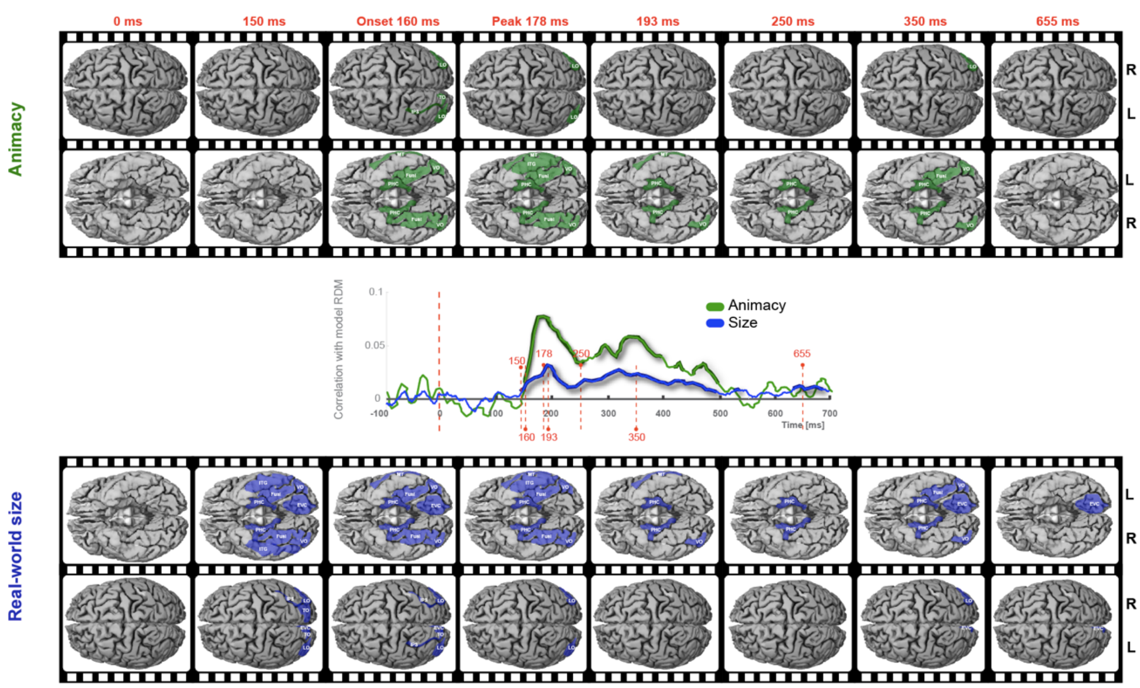

Fig 1. Spatiotemporal dynamics of size and animacy revealed by integrating MEG and fMRI data. The top and bottom row show snapshots of a spatiotemporally-resolved movie of animacy (top) and size (bottom) representation. Middle row shows the time-courses of size and animacy obtained by correlating MEG RDMs with size and animacy model RDMs over time. Shaded parts of the curves show statistical significance (sign-rank, FDR corrected, q<0.05)