Investigating Configural and Local Shape Processing with Steady State Visual Evoked Potentials

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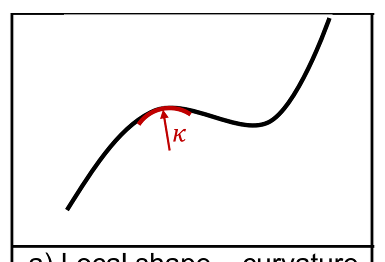
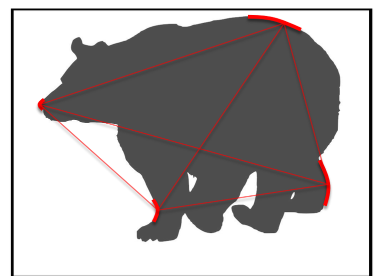
Background


a) Local shape – curvature


b) Configural shape

A large fraction of the visual cortex is devoted to object processing, and object shape information underlies our ability to detect, recognize and manipulate objects.

Object shape is comprised of both local and configural shapes. Previous research has led to the development of synthetic maximum-entropy shape stimuli that progressively match the natural curvature statistics but lack global regularities[1,2].

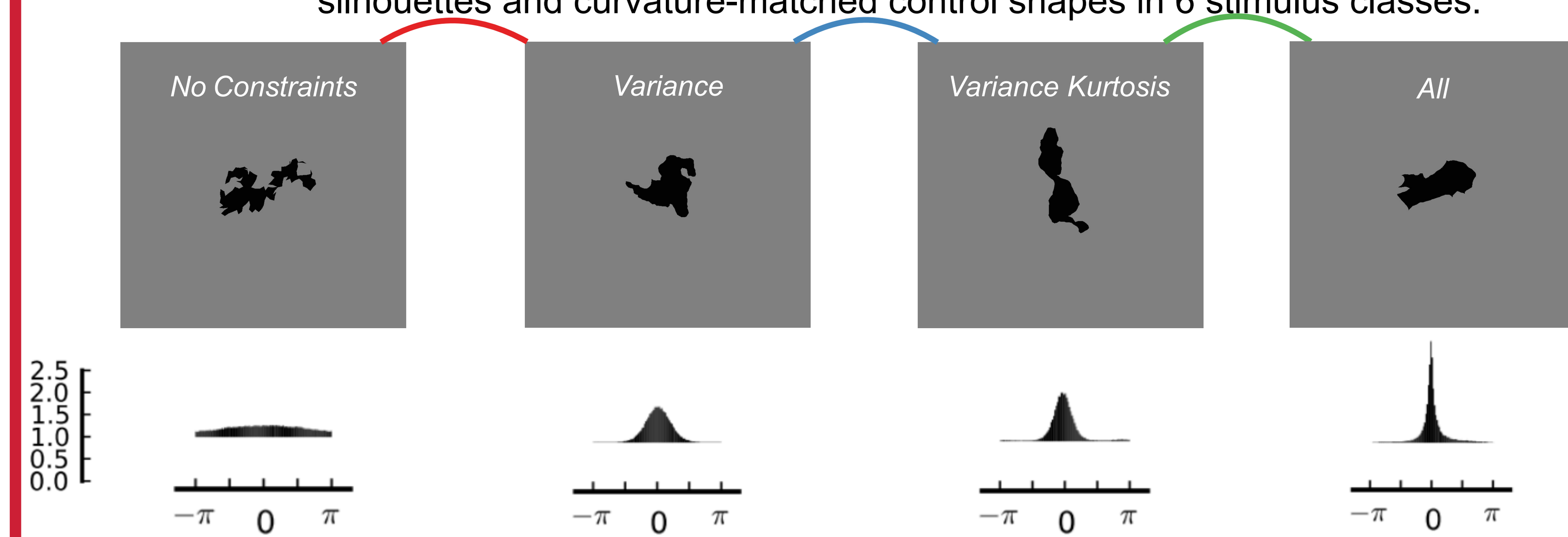
These stimuli have been used in behavioural experiments to dissociate local and configural shape processing, revealing profound sensitivity to both higher-order statistics of local shape, as well as configural shape information[1,2].

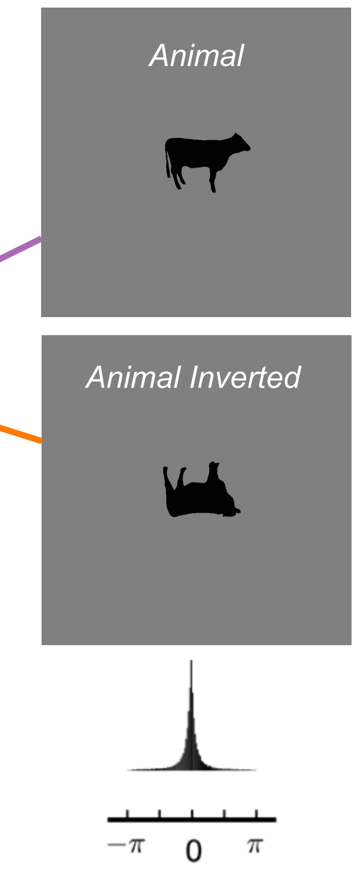
Here we use EEG to measure responses of the human visual system to investigate whether the brain responds to manipulations in curvature and configural shape.

Methods

Maximum Entropy Shape Stimuli

We employed a stepwise comparison of brain responses to animal silhouettes and curvature-matched control shapes in 6 stimulus classes.





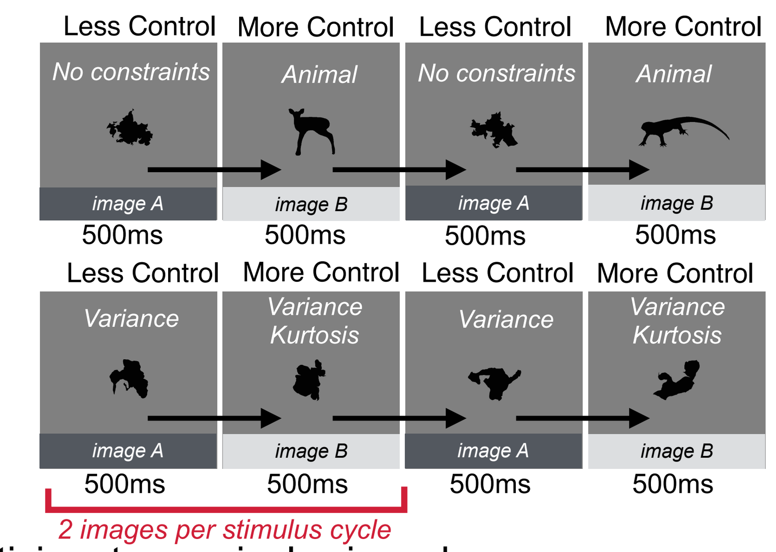
Curvature distribution with no constraints imposed.

Variance of the curvature distribution is matched.

Variance and Kurtosis are matched.

Curvature distributions fully matched.

Experiment Design



We used a Steady-State Visual Evoked Potentials[3] (SSVEPs) paradigm to investigate the cortical mechanisms that represent curvature statistics of objects silhouettes.

In each condition, n = 32 participants passively viewed a sequence of cycles, each cycle consisting of 2 images. Giving a stimulation frequency of 1 Hz.

Participants viewed 6 pairs of images in each trial.

Results

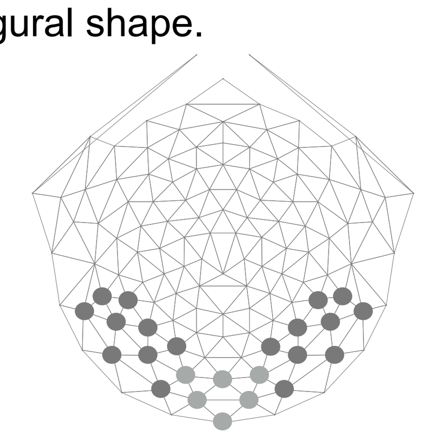
Here we present data from an electrode region-of-interest (ROI) over occipital and temporal cortex.

Waveforms

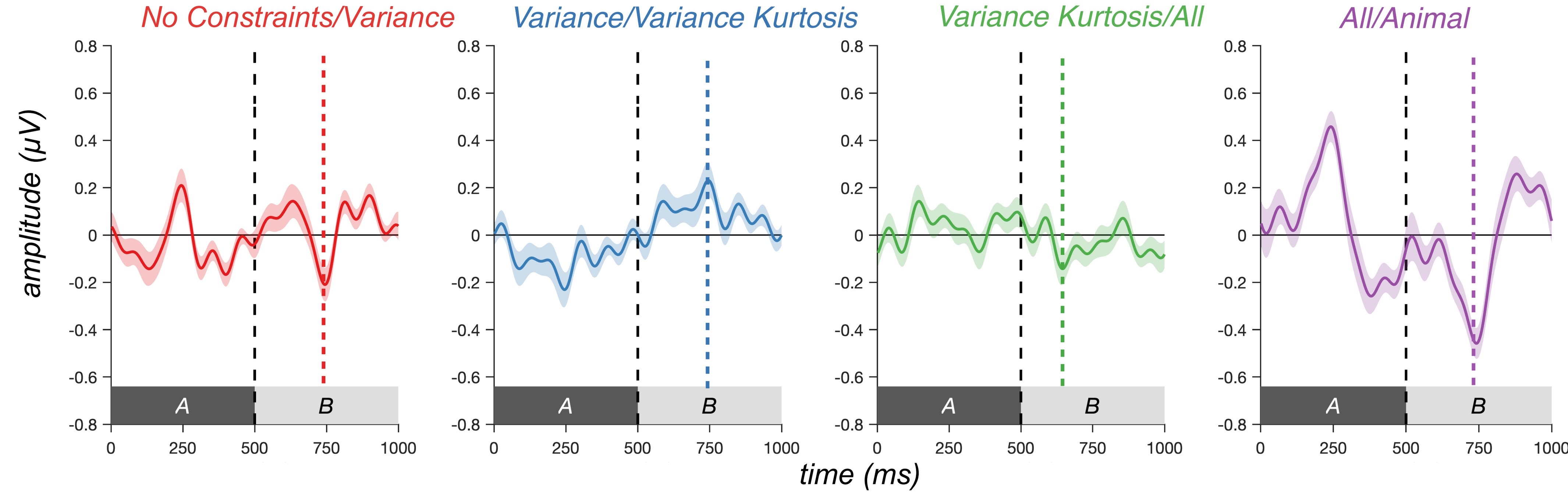
SSVEP data were filtered in the spectral domain and then projected back into the time domain to generate single cycle averages. Filtering was done separately for the first six odd and even harmonics. Based on previous work[3], we expect differences between the compared classes of stimuli to be isolated in the odd harmonics.

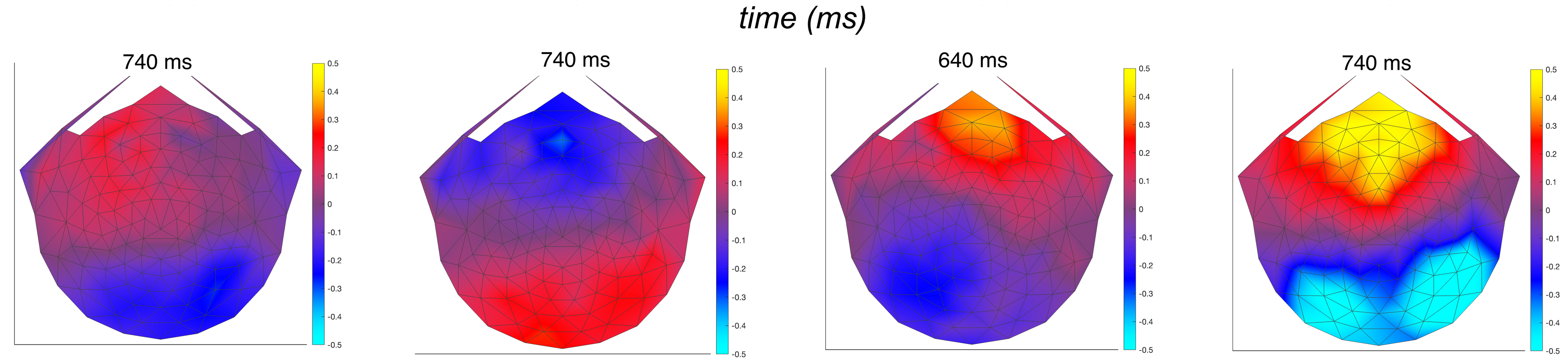
Topographies

Whole-scalp topographies based on filtered waveform data at peak responses for the odd harmonics. We find that objects generate differential activity in occipital and temporal cortex 170 – 290 msec post-onset, depending on both local curvature statistics and global configural shape.



Occipital ROIs





Comparing no constraints with variance shows a broad cortical response centred over the occipital cortex that peaks ~240ms after image onset.

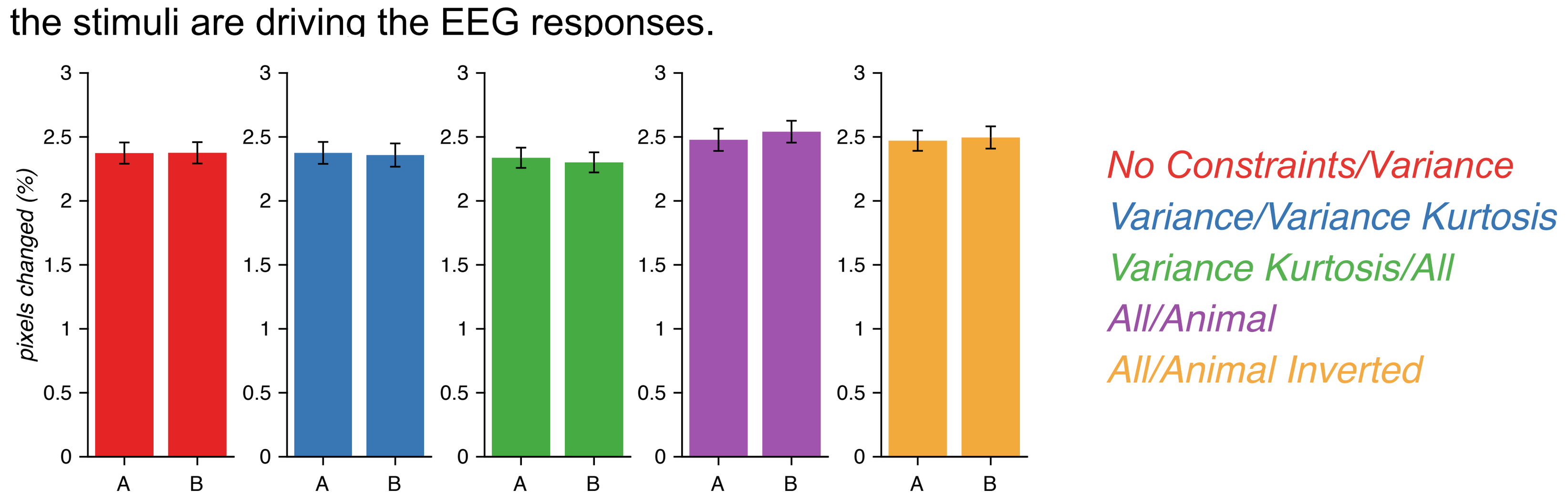
Variance compared with variance + kurtosis peaks ~240ms and is phase inverted compared with the other responses.

Comparing variance + kurtosis with All peaks ~140ms after image update and shows additional higher-order moments result in a possibly left-lateralized response.

The comparison between all statistics and animals reveals a strongly right-lateralized response.

Image Analysis

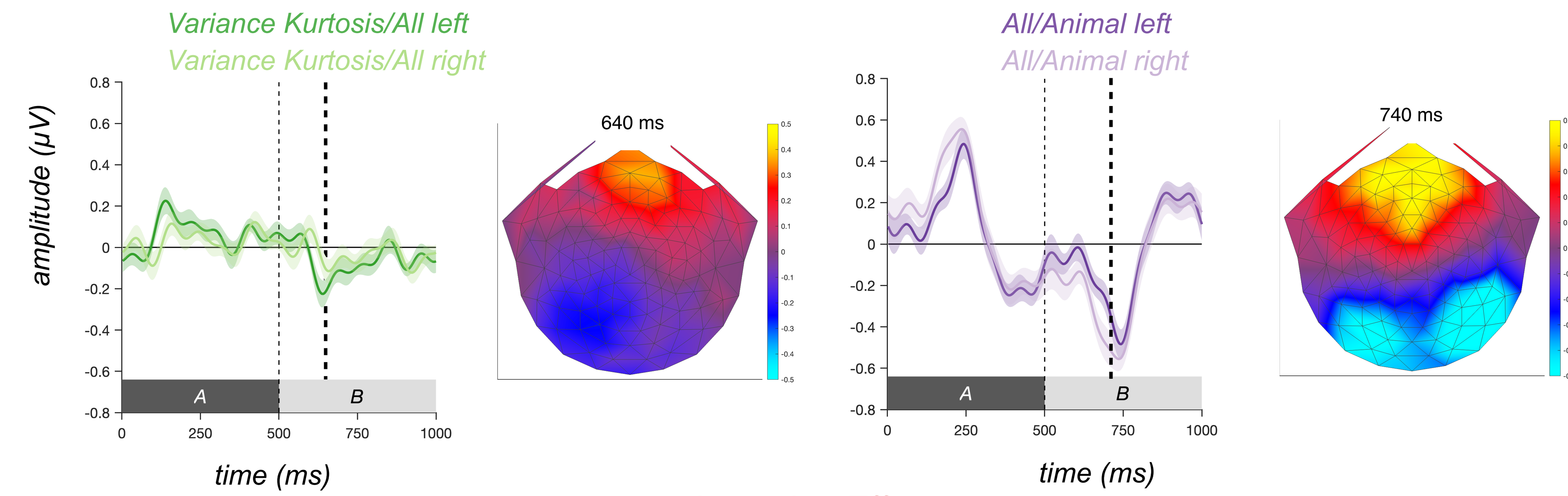
We ensured that our stimuli are well controlled via an image analysis calculating the average pixel change across all trials and all cycles, confirming that our manipulations to the stimuli are driving the EEG responses.



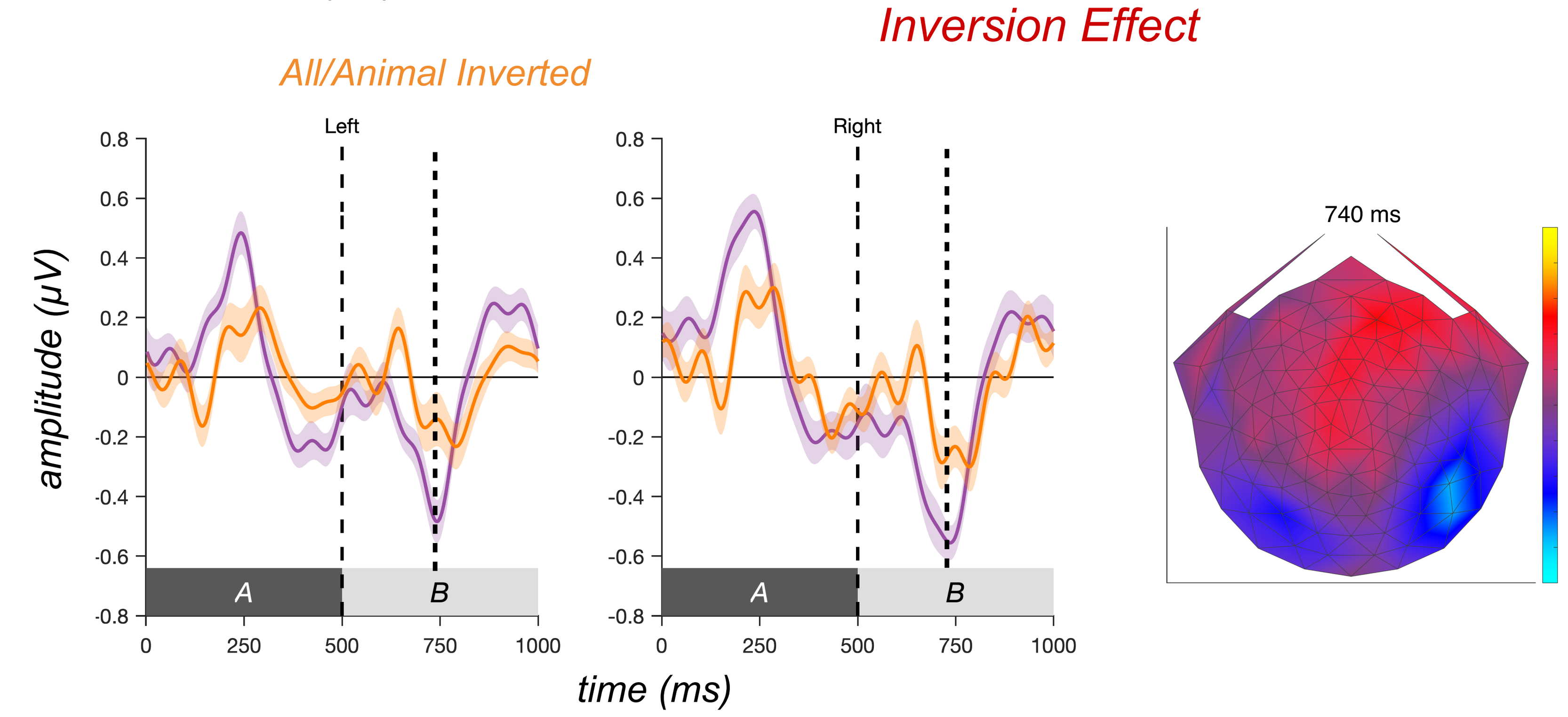
Lateralized Responses

The response in the left hemisphere appears to lead the right hemisphere by ~30ms.

The response in the right hemisphere appears to lead the left hemisphere by ~50ms.



Inversion Effect



Contrasting all statistics with inverted animals reveals a strong inversion effect. A hallmark of holistic/ configural processing.

Conclusions

The human visual system responds to manipulations in curvature and configural shape.

The visual system is sensitive to stimuli matching the variance of curvature distribution, but matching kurtosis, offers limited value-add.

Additional higher-order moments by matching the curvature distribution results in a possible left-lateralized response.

Natural animal shape produce distinguishable responses from control stimuli with completely matched curvature distributions, with the response being right-lateralized.

Inverting the animal shape diminishes the configural response but does not eliminate it. Suggesting that some aspect of configural processing survives inversion.

References

1. Elder, J. H., Oleskiw, T. & Fründ, I. The Role of Global Cues in the Perceptual Grouping of Natural Shapes. Journal of Vision 18, 1–21 (2018).
2. Fründ, I. & Elder, J.H. (2015). Tuning of the visual system to the curvature natural shapes, Computational and Systems Neuroscience (COSYNE)
3. Kohler, P. J., Clarke, A., Yakovleva, A., Liu, .Y & Norcia, A. M. (2016). Representation of maximally regular textures in human visual cortex. Journal of Neuroscience, 36(3), 714 –729.