Investigating Local and Configural Shape Processing with SSVEPs

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European Conference on Visual Perception
Monday Aug 26th, 2024

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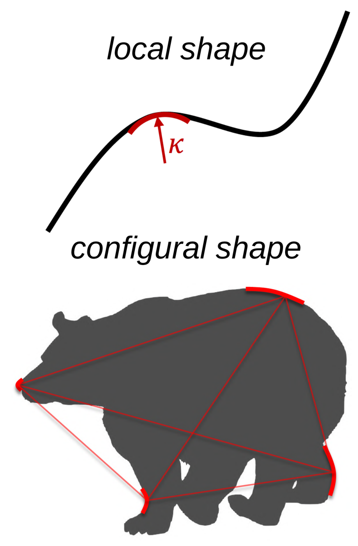
Background

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

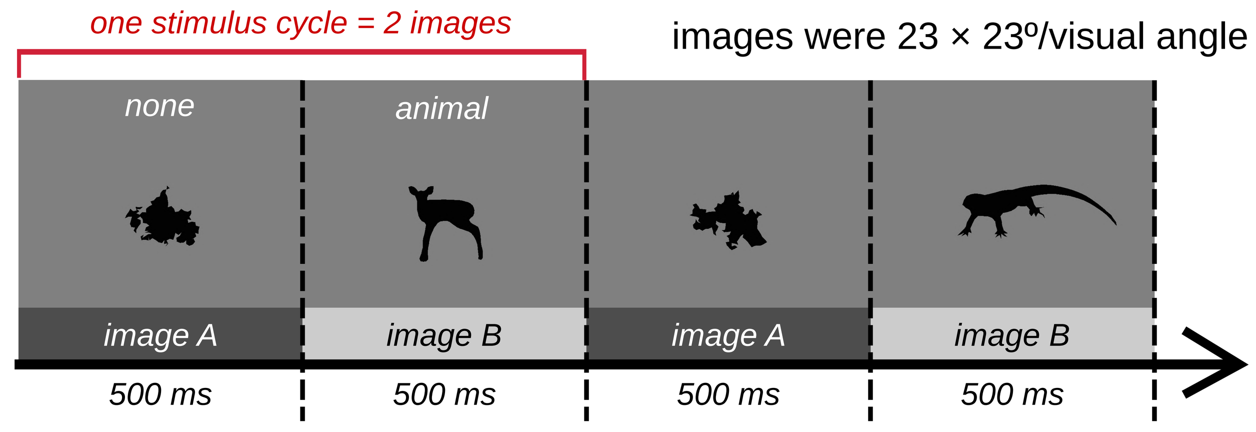
Object shape is comprised of both local and configural shape information. Behavioural experiments have revealed that profound sensitivity to both higher-order statistics of local shape, as well as configural shape information[1,2].

Here we use EEG with a Steady-State Visual Evoked Potentials (SSVEP) paradigm that allows us to isolate responses from the human visual system that are driven by local curvature statistics of natural shapes. In a separate study, we use the same approach to measure responses to configural shape information.



Experiment Design

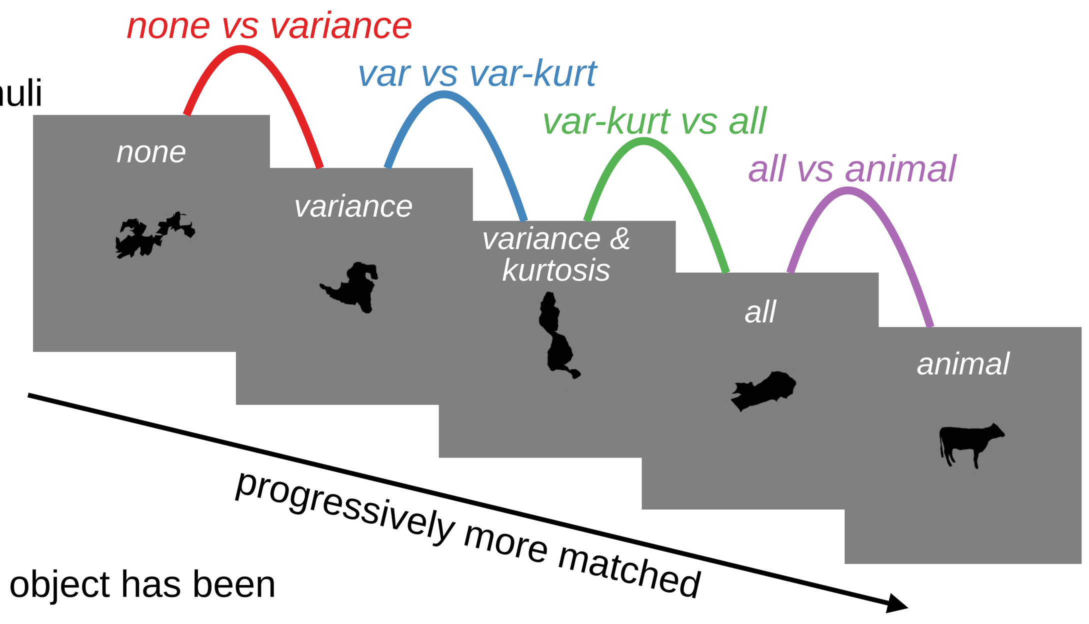
- stimuli shown periodically to elicit periodic steady-state responses in visual cortex
- "less natural" image class was always shown first
- 12 cycles per trial, first and last cycle excluded from analysis
- 12 images per class per trial, each image shown once per experiment
- 30 trials per condition



Stimuli

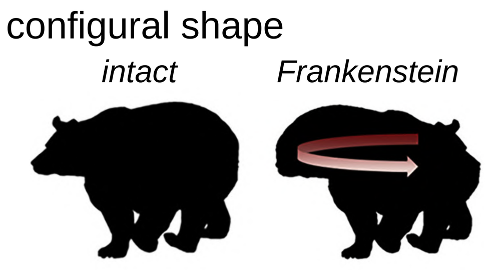
Study 1

- synthetic, maximum-entropy shape stimuli
- progressively match the curvature distribution of natural shape silhouttes, from unconstrained ("none") to fully matched ("all"), but have no configural shape information[1,2]
- pairing image classes lets us measure sensitivity to these local statistics



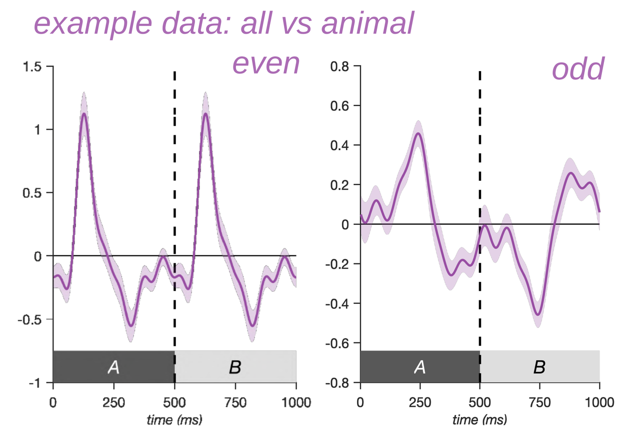
Study 2

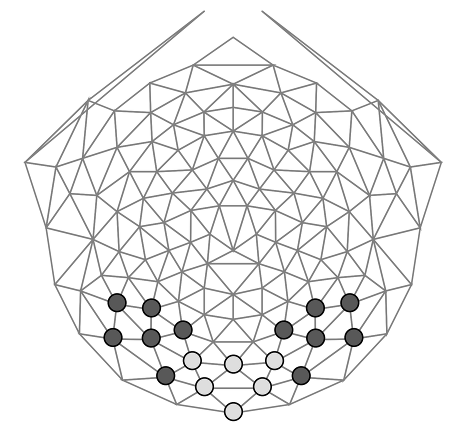
- "Frankenstein" stimuli: upper half of the object has been flipped relative to the lower half
- disrupts object recognition in human observers[3], while preserving local and configural shape
- to directly relate our brain data to human object recognition performance, we paired Frankenstein and intact stimuli for shapes where Frankensteining had a strong and weak behavioral effect



Data Analysis

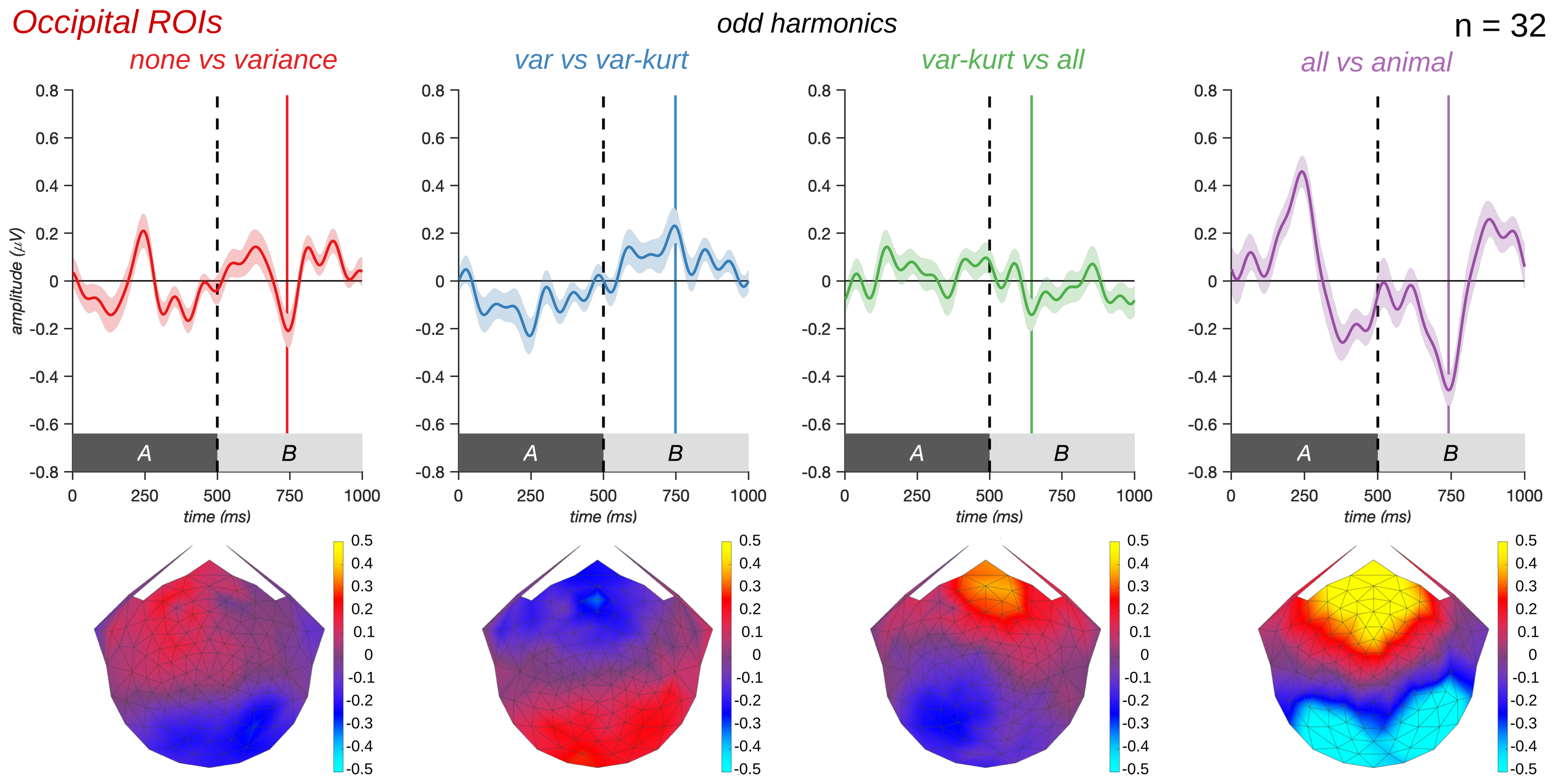
- high-density EEG was collected using a 128-electrode Magstim EGI Geodesic Sensor Net
- SSVEP data was filtered in the spectral domain and then projected back into the time domain to generate single-cycle average timecourses, containing signal from the first six odd and even harmonics
- even harmonics capture brain responses that are the same for the two image classes shown, likely dominated by relatively low-level image-update responses
- as expected, even harmonics were for the most part identical across all conditions in our two studies
- odd harmonics will capture brain responses that differ between the two image classes[4] and therefore allows us to isolate responses driven by our shape manipulations
- our analysis focused on three electrode regions-of-interest: One over occipital cortex, and two over left and right temporal cortices





Results: Study 1

Occipital ROIs



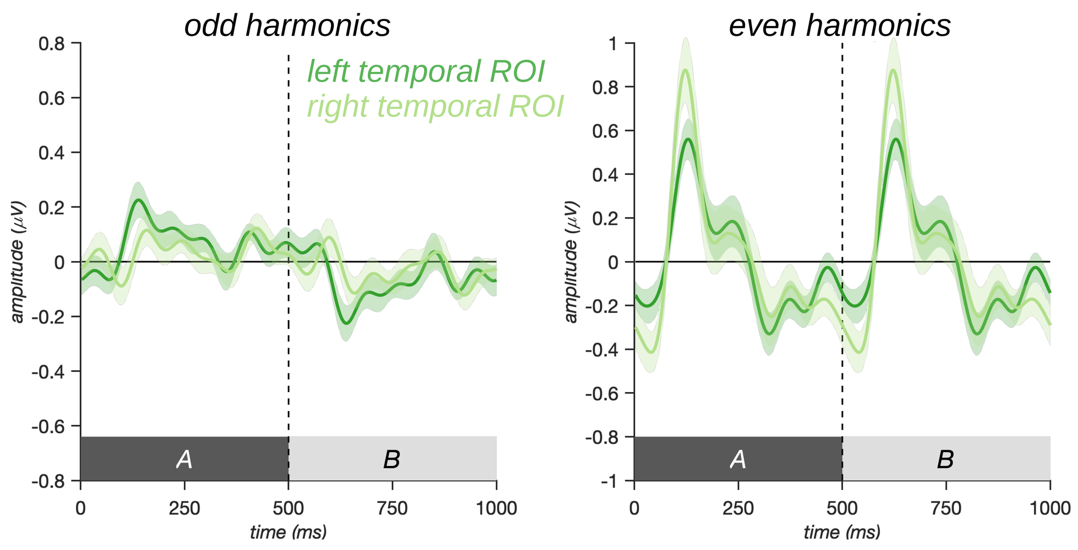
none vs variance produced responses peaking 240 ms after image update, with broad topography centered over occipital cortex

all vs animal produced the largest response of all conditions, again peaking at 240 ms, with topography suggesting involvement of temporal regions

Temporal ROIs: Hemisphere comparisons

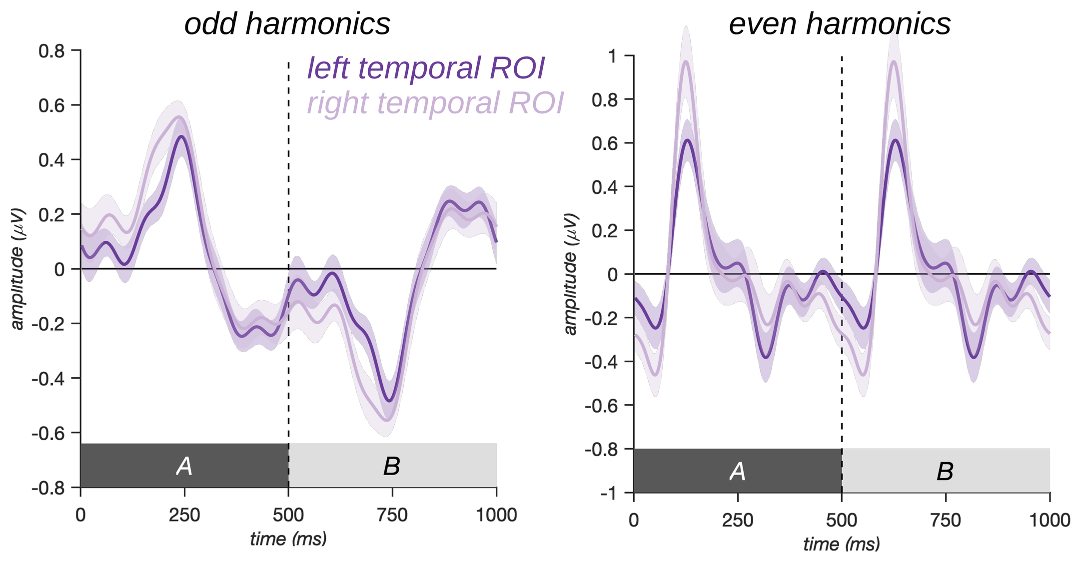
var-kurt vs all

- modest response in occipital ROIs, but somewhat larger in temporal ROIs, especially on the left side
- the left hemisphere ROI lead the right hemisphere by ~30 ms
- for the even harmonics, amplitudes were higher in the left hemisphere, and there was no timing difference



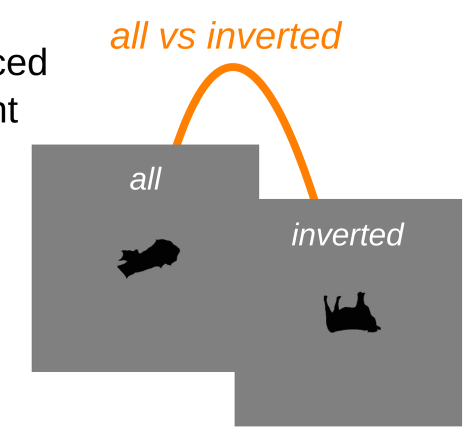
all vs animal

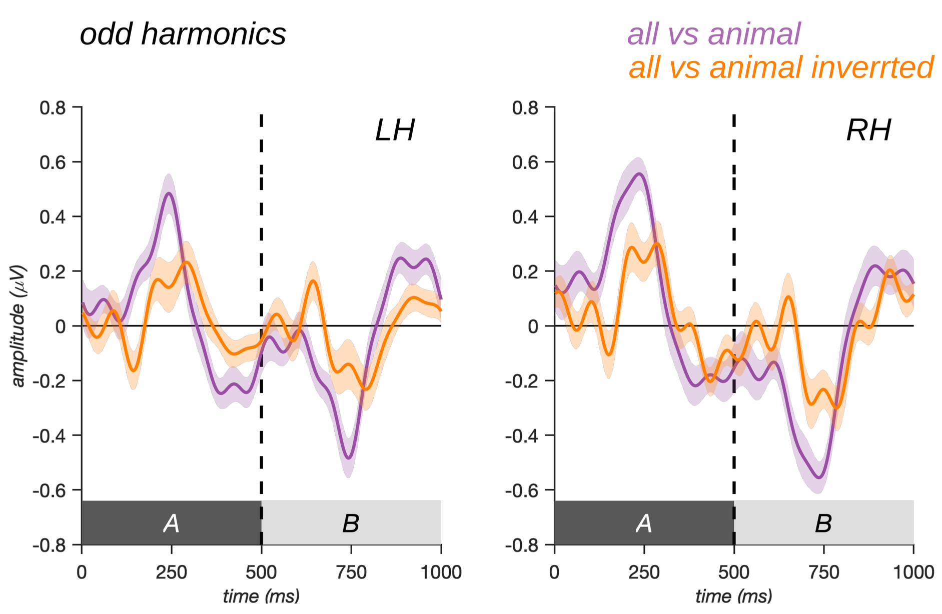
- the right hemisphere temporal ROI lead the left by ~50 ms
- weak or no amplitude effect
- for even harmonics, amplitudes were higher in the right hemisphere, and there was no timing difference



Temporal ROIs: Inversion effect

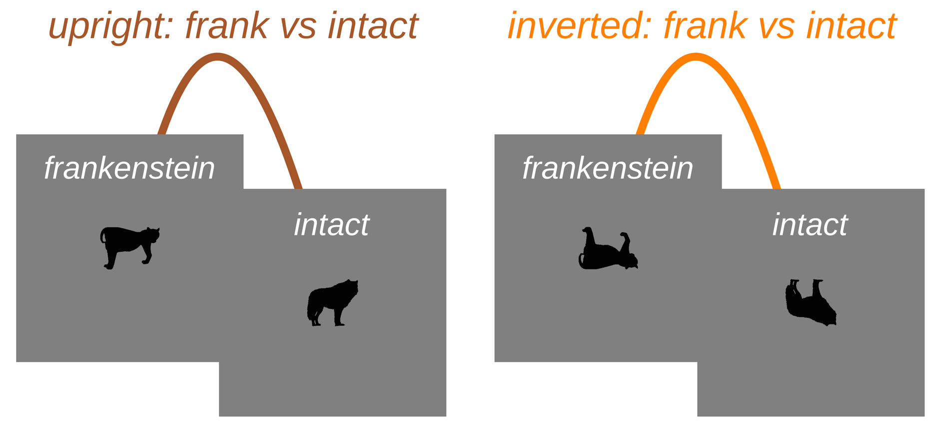
- we ran another condition comparing the fully matched stimulus ("all") to inverted versions of the animal shape silhouettes
- response was reduced relative to the upright condition, but not eliminated
- some configural processing survives



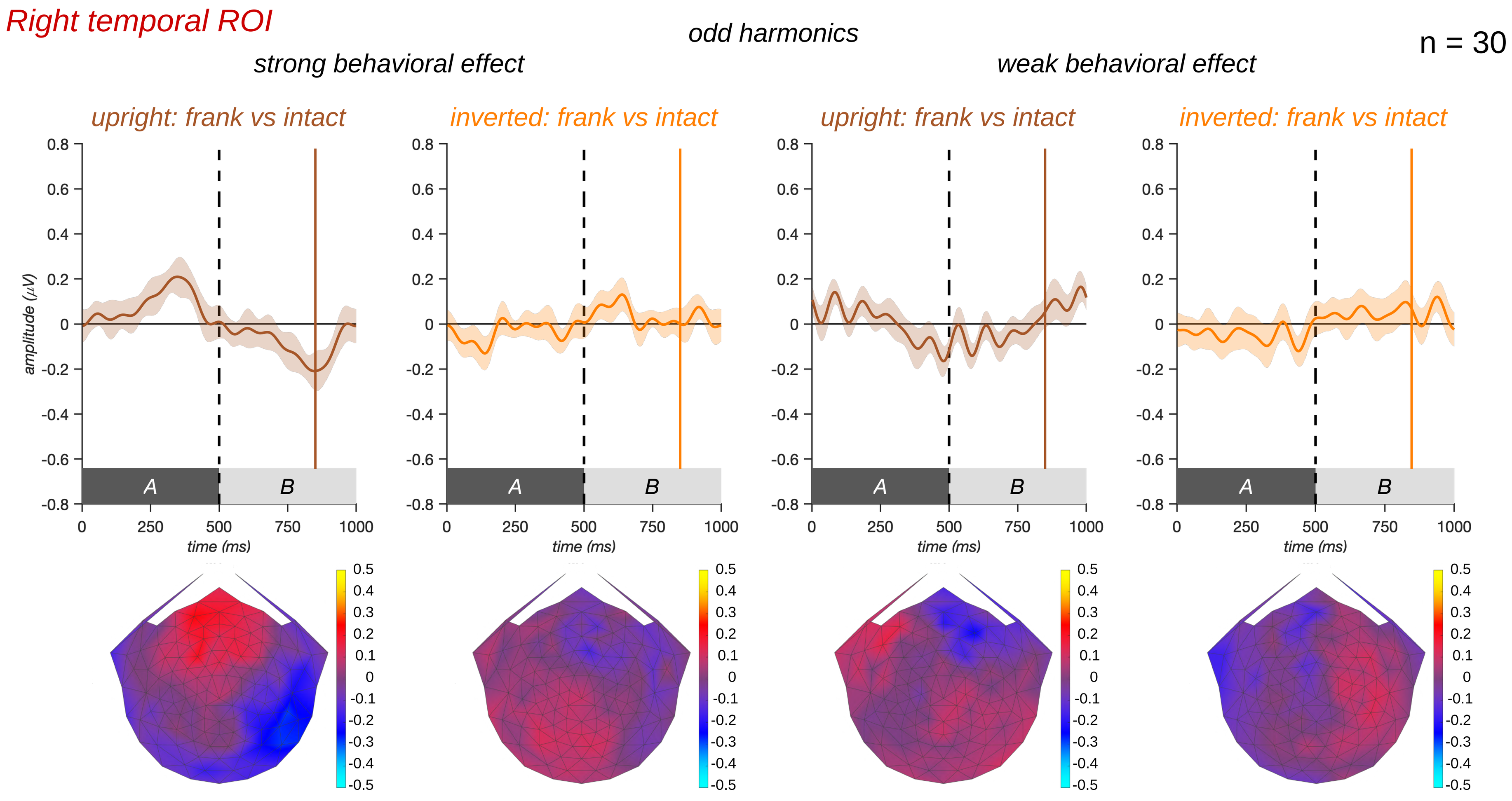


Results: Study 2

- for both the strong and weak behavioral effect condition, we also ran a version where both the frankenstein and intact shapes were inverted
- object exemplars were always mismatched between frankenstein and intact shapes within each pair, to avoid apparent motion and systematic differences at the pixel level between the first and the second image update



Right temporal ROI



- responses were more modest overall, compared to the all vs animal condition in Study 1
- responses were largest in right temporal ROI and peaked later than in Study 1, around 350 ms
- responses were strongly modulated both by inversion and strength of the behavioral Frankenstein effect

Conclusions

The visual system is sensitive to the variance of the local curvature distribution, but not kurtosis. Stimuli that are matched in terms of additional higher-order moments, produces a possibly left-lateralized response.

Natural shapes produce highly robust, right-lateralized responses when compared to control stimuli with fully matched local curvature distributions. Inverting the shapes reduces this response, but does not eliminate it, suggesting that some aspects of configural processing survive inversion.

Intact natural shapes produce right lateralized responses when compared to Frankenstein stimuli, that peak 100 ms later than those produced when comparing natural shapes and fully matched synthetic shapes. These responses are only found for stimulus sets that produce a behavioral effect on object recognition, and are eliminated by inversion, suggesting that they capture a neural signature of object recognition.

References

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Supported by The Natural Sciences and Engineering Research Council of Canada, The Canada First Research Excellence Fund, and The Faculty of Health at York University.

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