Steady-state visual evoked potentials reveal parietal contributions to abstract numerosity

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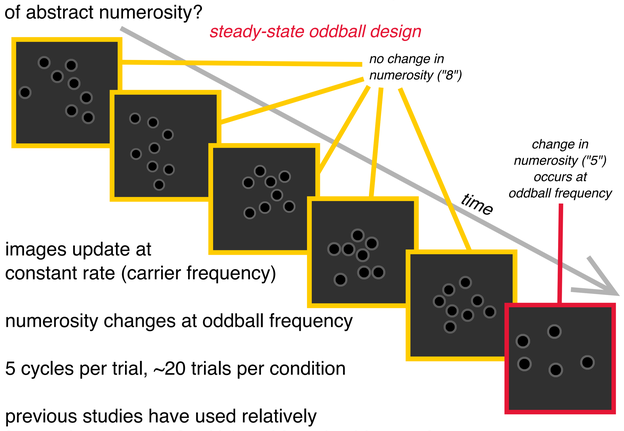
Background

Can SSVEPs be used to measure neural computation of abstract numerosity?



images update at constant rate (carrier frequency)

numerosity changes at oddball frequency

5 cycles per trial, ~20 trials per condition

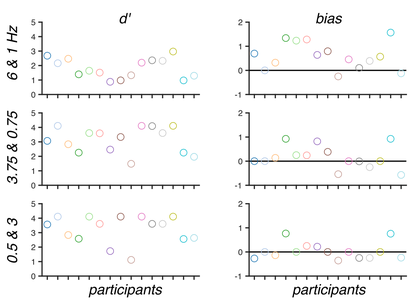
previous studies have used relatively fast update rates (8 & 1 Hz) and found evidence of number processing in electrodes over occipital cortex[1]

Numerosity change detection task

At the end of each trial, participants were asked to report whether or not there had been a change in numerosity.

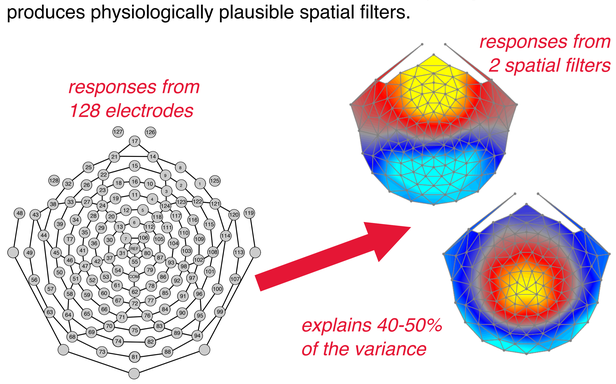
Sensitivity was weakest in the 6 & 1 Hz case, but consistently above-chance when number changed by 3.

When number changed by 1 (Experiment 2, data not shown) sensitivity was near chance.



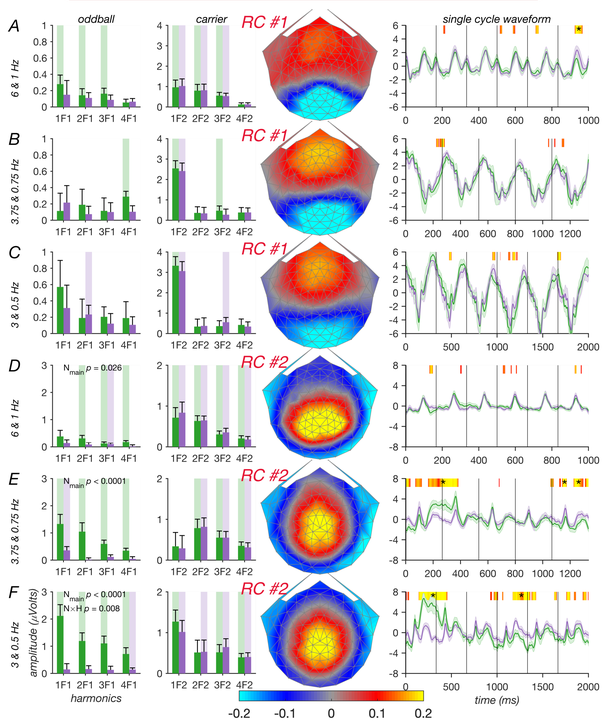
Reliable Components Analysis

A method of spatial dimensionality-reduction2 that maximizes between-trial covariance, can be applied in the time- or frequency domain and produces physiologically plausible spatial filters.



Experiment 1: Temporal tuning

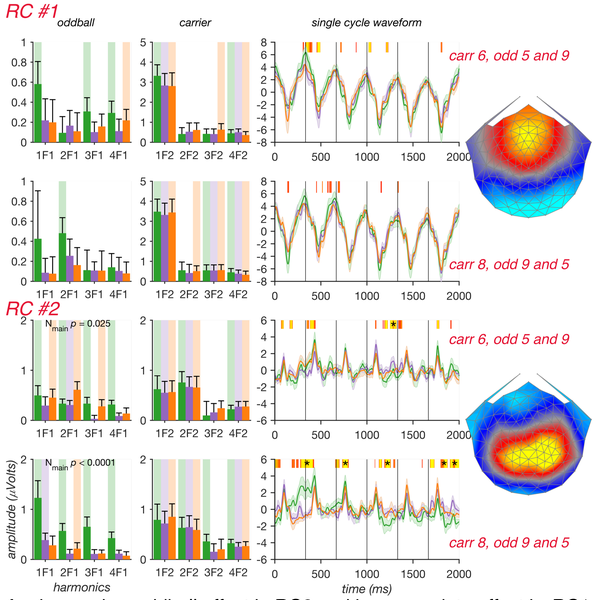
n = 15 *carrier* = 8 *oddball* = 5 3 frequency pairs



RC1 captures image update response, while number-oddball effect is found in *RC2*, and is strongest for slow presentation rates.

Experiment 2: Varying distance

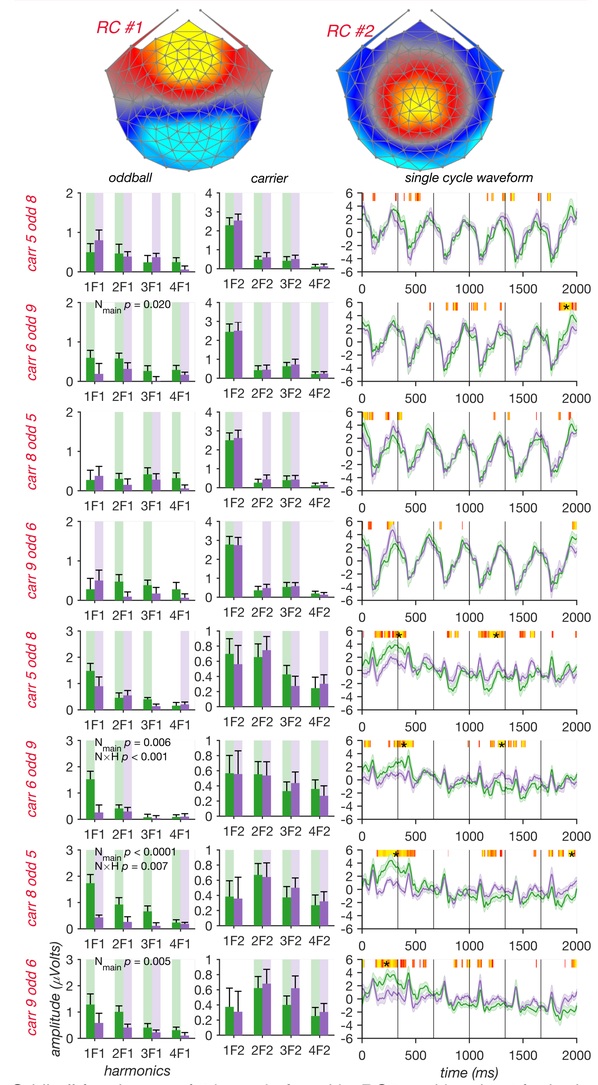
n = 15 *carriers* = 6 & 8 *oddball* = 5 & 9 3 & 0.5 Hz



Again, number-oddball effect in RC2 and image-update effect in *RC1*, but oddball effect only measurable when the change in numerosity is 3 and is much weaker for increases in numerosity than for decreases.

Experiment 3: Does direction matter?

n = 15 *carriers* = {5, 6, 8, 9} *oddball* = {8, 9, 5, 6} 3 & 0.5 Hz



Oddball for change of 3 is again found in *RC2*, and is robust for both increases and decreases, although carrier 5 paired with oddball 8 does not produce a significant response in the frequency domain.

Conclusions

Across 3 experiments, SSVEPs measured with relatively slow presentation rates (3 & 0.5 Hz) consistently produce two response components, centered over parietal and occipital cortex.

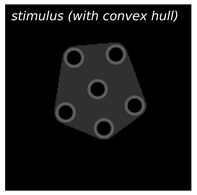
The occipital component mostly captures responses driven by image updates, while the *parietal component captures responses related to changes in numerosity at the oddball frequency.*

The SSVEP oddball paradigm could provide the foundation for creating a rapid and portable neurometric approach to quantifying number sense in educational settings.

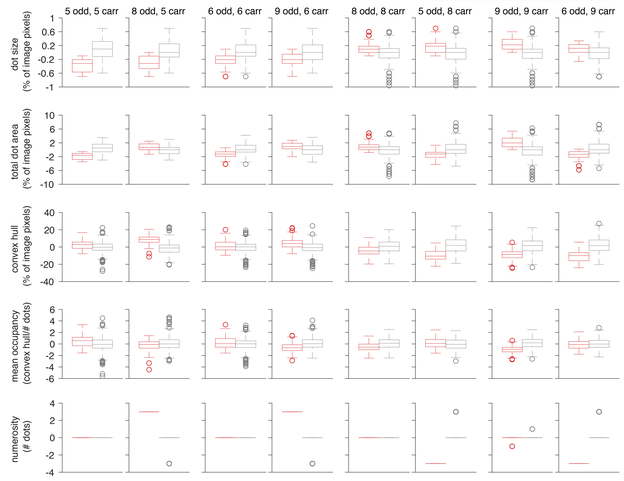
How well-controlled were the stimuli?

Stimulus parameters

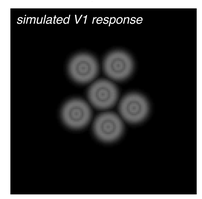
We assessed five distinct parameters for each update over 10 trials of data:
1) dot size 2) total dot area 3) convex hull 4) mean occupancy 5) number of dots



change from previous image update (**oddball** vs **carrier**)



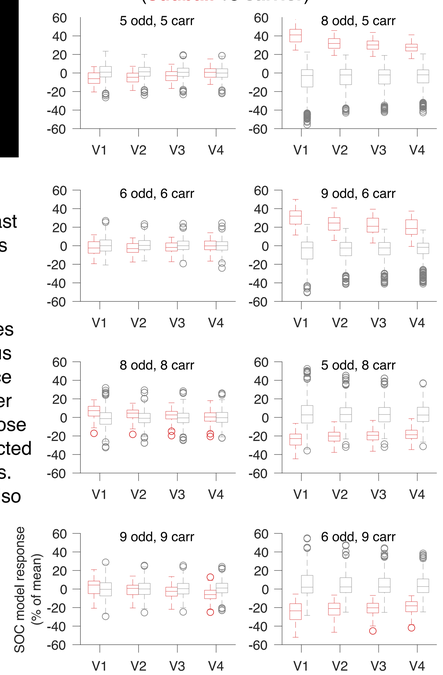
Visual responses



We passed the images through a second order contrast model that simulates responses[3] in visual areas V1-V4.

There are differences between the stimulus changes taking place at oddball and carrier dot updates, and those diferences are detected by early visual areas. However, there is also substantial overlap in both stimuli and responses.

change from previous image update (**oddball** vs **carrier**)



References

[1]Park J (2018) A neural basis for the visual sense of number and its development: A steady-state visual evoked potential study in children and adults. *Developmental Cognitive Neuroscience* 30:333-343.

[2]Dmochowski JP, Greaves AS, Norcia AM (2015) Maximally reliable spatial filtering of steady state visual evoked potentials. *NeuroImage* 109:63-72.

[3]Kay KN, Winawer J, Rokem A, Mezer A, Wandell BA (2013) A two-stage cascade model of BOLD responses in human visual cortex. *PLoS computational biology* 9:e1003079.