Frequency tagging of chromatic stimuli reveal distributed occipital activity in response to illusory surfaces and concentrated activity in response to real surfaces

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Introduction

- The complete perception of chromatic surfaces depends on information from both the wavelength properties of the surface, and from luminance contrast at its edges (figure 1a; Shapley & Hawken, 2011).
- In the absence of surface information, our brain will use edge information to help us fill in the most likely percept, an effect which is enhanced through attention (de Weerd, 2006; figure 1b).
- In our study, we use variations of the watercolour illusion to examine the extent to which surface, edge and filling-in mechanisms contribute to surface perception, and measure cortical responses to chromatic surfaces using EEG.

Hypotheses

1. Visible edges enhance the perceived saturation of chromatic surfaces.
2. Illusory filling-in occurs on filled surfaces in addition to white surfaces.
3. Stimuli with higher levels of perceived saturation will evoke higher amplitude ERPs.

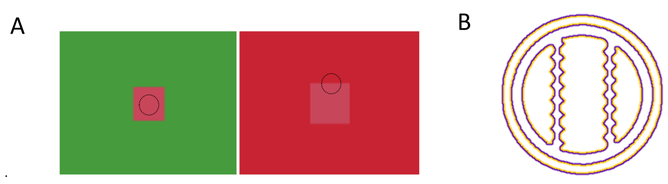

Figure 1. **A**. The Colour contrast effect. Hypothetical surface and edge detector RFs are highlighted with dashed lines . **B**. The watercolour illusion (Pinna et al., 2001).

Experiment 1: Psychophysics

- The objective of the experiment 1 was to measure the perceived saturation (point of subjective equality; PSE) of our target stimuli using a 2AFC staircase paradigm (figure 3).
- Target stimuli 3-6 were filled with a saturation intensity of 0.175 (figure 2).

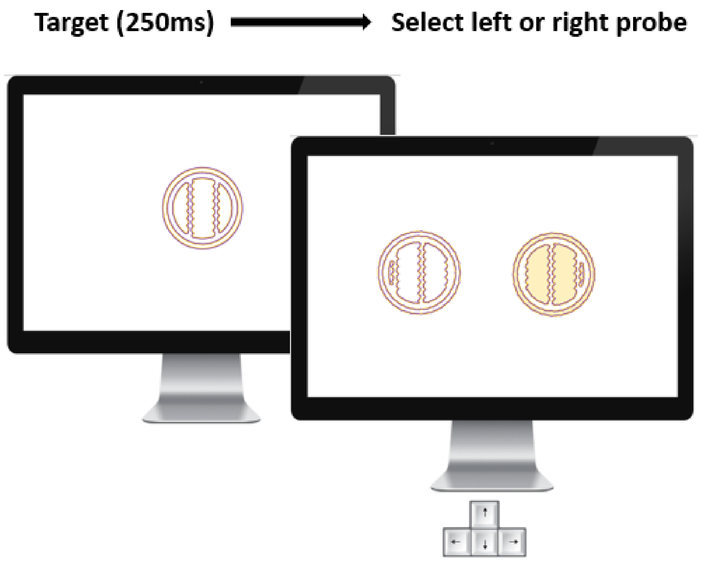

Figure 3. Participants selected the probe that better resembled the target stimuli's surface saturation. The perceived saturation of our six target stimuli were determined in this manner. The probe stimuli were always braided.

Methods

- 20 observers participated in the psycophysics experiment and 20 participated in the EEG experiment. 12 observers participated in both experiments.
- Six chromatic stimuli were generated for the purposes of our research questions (diameter = 5.12°; figure 2).

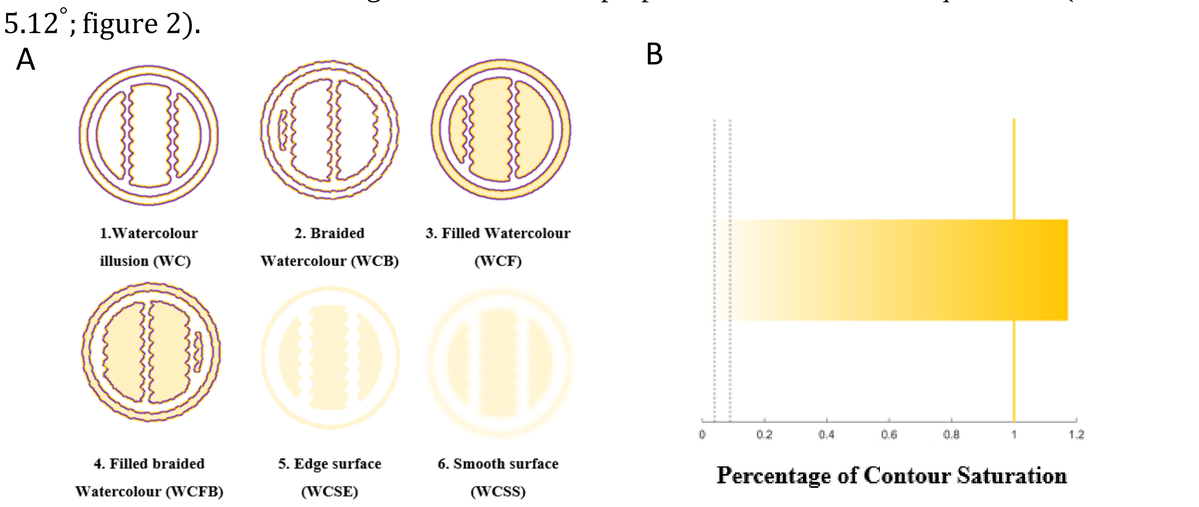

Figure 2.A Illustration of visual stimuli. Stimuli 1-4 are outlined with orange and purple contours. The columns of stimuli 3-6 are filled with a desaturated shade of orange. **B.** The saturation intensity of the surfaces are modulated on a vector based on the saturation of the inner orange contour. The first and second dashed x lines indicate the perceived saturation of stimuli WCB and WC respectively, obtained from our behavioural experiment.

Experiment 2: EEG

- Participants were asked to maintain fixation while the visual stimuli alternated at 4Hz during a 15 second trial (figure 4). Observers were instructed to press the spacebar if a filled gray oddball stimulus appeared (9 trials). Data from these trials were omitted from analysis.
- Target stimuli were frequency tagged at 2Hz in the experimental conditions (Table 1).
- 64 channel EEG, ROI= Oz, O1, O1, PO8, PO7.

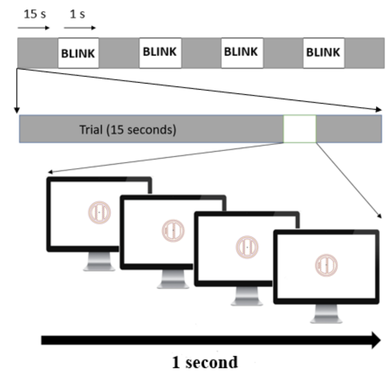

Figure 4. An example trial is shown. There were 5 trials in a block and 20 blocks in a run. The example trial is from experimental condition 1.

Condition		Experimental		Control	
A	Stim	WC	WCB	WCB	WCB
	Sat	0	0	0	0
B	Stim	WCFB	WCB	WCB	WCB
	Sat	≥ .09	0	0	0
C	Stim	WCSE	WCSS	WCSS	WCSS
	Sat	≥ .09	≥ .09	≥ .09	≥ .09
D	Stim	WC	WCF	WCF	WCF
	Sat	0	≥ .09	≥ .09	≥ .09

Table 1. Changes in stimulus presentation occur in the experimental conditions. Chromatic surfaces were filled with a saturation intensity of .09, based on the WC PSE from our behavioural experiment. Note that control conditions A and B are the same. Stim = stimulus. Sat = saturation.

Results

Experiment 1: The WC stimulus successfully evoked a filling-in effect. Filling-in also occurs on filled surfaces. Visible edges do not enhance the apparent saturation of surfaces.

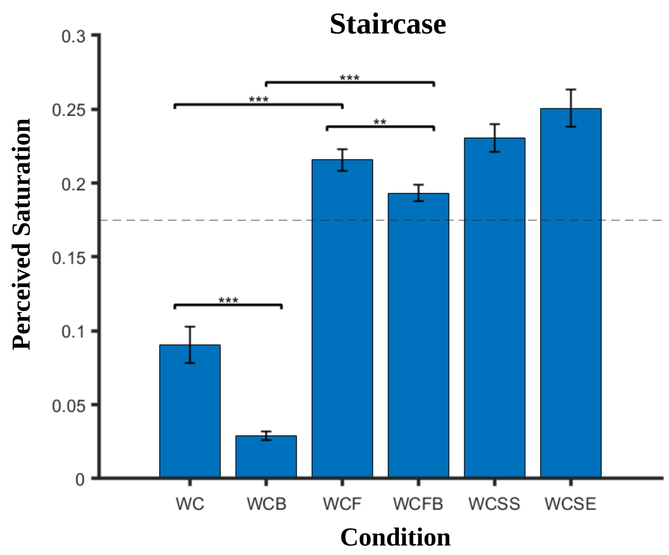

Figure 5. 12 of the 20 observers performed the staircase with the WCSE target. Dashed y-line reflects true saturation of filled stimuli. Bonferroni corrections were applied. Significance calculated with two tailed t-test,**p < .01*. ****p < .001*.

Experiment 2: Illusory colour evokes a high amplitude ERP across occipital channels whereas this effect is concentrated to electrode Oz for real colour. Contourless stimuli evoke weak ERPs. Attention related effects are evident in the alpha band.

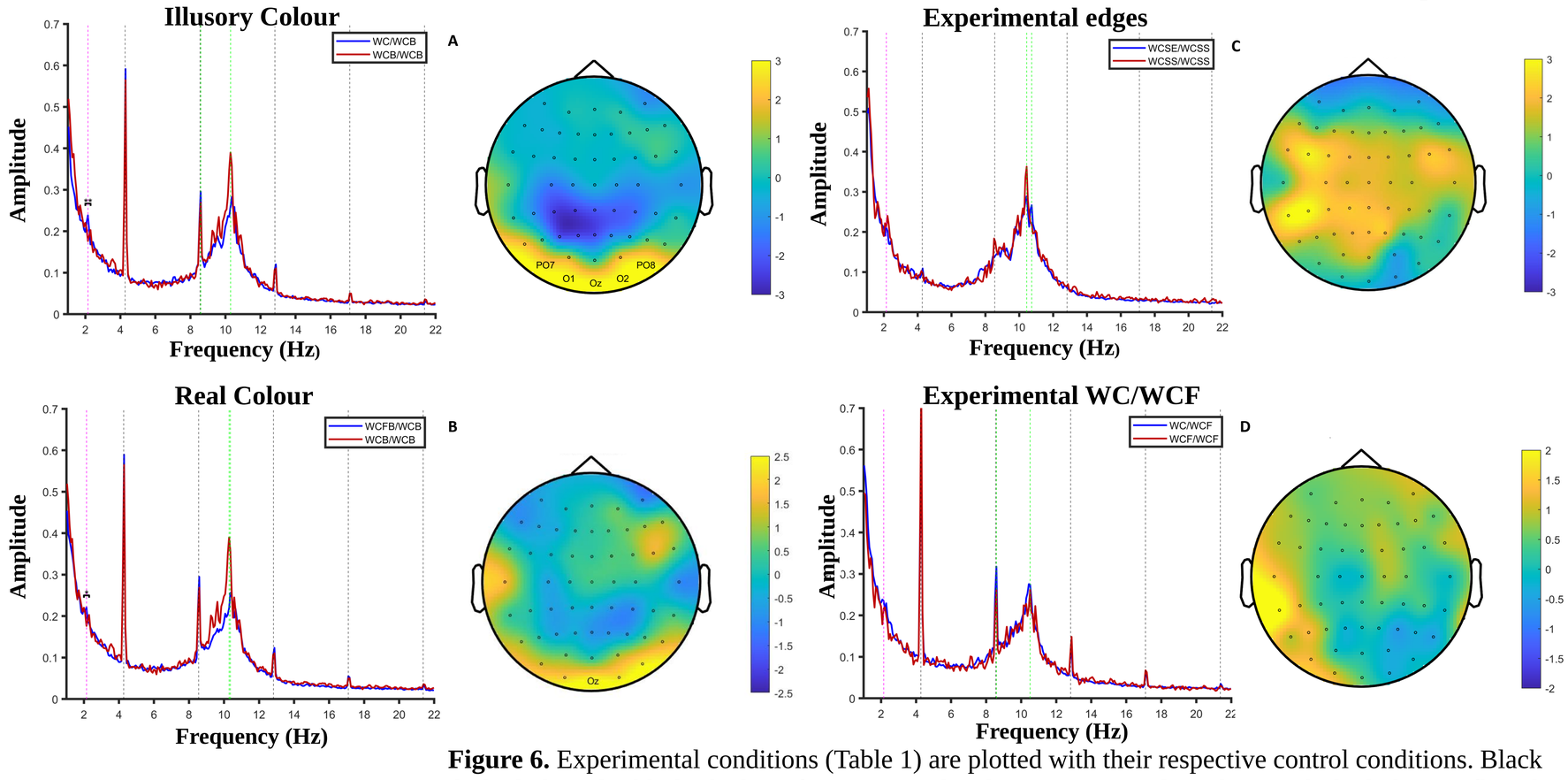

Figure 6. Experimental conditions (Table 1) are plotted with their respective control conditions. Black dashed xlines highlight the base frequency and its harmonics. Purple and green dashed xlines reflect the 2Hz ERP and Alpha peak respectively. T-stats (colorbar) were Bonferroni corrected. Labelled channels are statistically significant *$p < .05$. **$p < .01$.

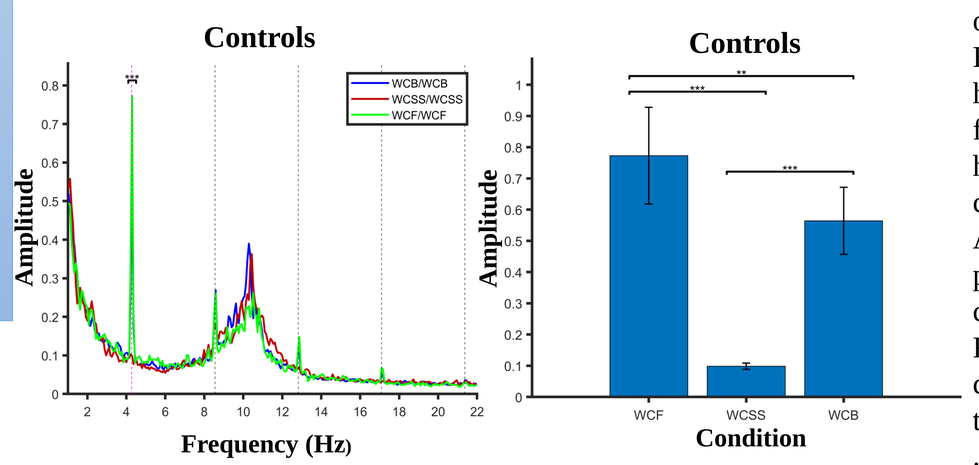

Figure 7.A Powerspectra of control conditions. Black dashed vertical lines highlight the base frequency and its harmonics. Significance calculated with RM ANOVA **B**. 4Hz ERP power of control conditions averaged over ROI. Bonferroni corrections were applied to t-tests. **$p < .01$. ***$p < .001$.

Conclusions

- Behavioural and electrophysiological results suggest that perceptual filling-in of illusory surfaces leads to a spread in neural activity across occipital channels.
- Real surfaces evoke ERPs concentrated to channel Oz.
- ERP amplitude is largely dominated by responses to contours of high luminance, as reflected by the weak ERPs of WCSS and WCSE stimuli.
- The inhibited alpha band response to WC, WCFB, and WCF stimuli is likely due to the enhanced attention that is required during surface completion.
- Activity from occipital channels is determined by the perceptual rather than physical attributes of colour.

References

- De Weerd, P., Smith, E., & Greenberg, P. (2006). Effects of selective attention on perceptual filling-in. *Journal of Cognitive Neuroscience*, *18*(3), 335-347.
- Pinna, B., Brelstaff, G., & Spillmann, L. (2001). Surface color from boundaries: a new 'watercolor' illusion. *Vision Research*, *41*(20), 2669–2676.
- Shapley, R., & Hawken, M. J. (2011). Color in the cortex: single- and double-opponent cells. *Vision Research*, *51*(7), 701–17.