The Popple Illusion – playing games with your visual perception skills

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Abstract

One of the most famous Popple Illusions represents a perfect circle made of several Gabor patches – sinusoidal gratings convolved with a Gaussian filter. Their phase-shift induces a visual illusion, leading to the impression of seeing a square-like circle. In order to analyze which parameters influence the illusion and to what extent, we presented 37 subjects with ten variations of the illusion and a slider to 'correct' the visual effect. We found that the subjects significantly corrected the circle up to a distorted state, implying a strong visual illusion at first. Concerning the parameters, we found that the number of patches negatively correlated with the amount of correction; and a larger shift factor lead to an increase in distortion.

Introduction [Marina]

In 1908, the British psychologist Sir James Fraser showed that a line made of small tilted elements appears to be tilted, in the same direction of the elements. This illusion was then modified and recreated using another kind of elements: Gabor patches (Fig. 1) (Popple et al., 1999). Gabor patches are sinusoidal gratings (Fig. 2) – a series of alternating white and black bars, being small or big, stationary or rotating, and can be oriented in any direction. Since they are able to elicit specific responses in neurons in the early visual system (V1) and can therefore evoke activity in a controlled fashion, they are extremely common in visual experiments.

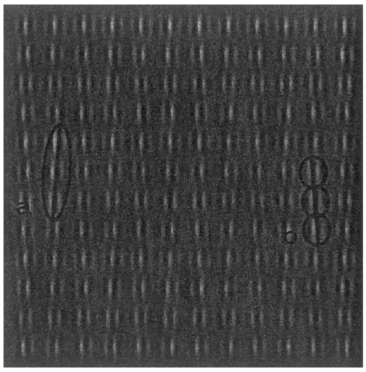

Fig. 1. The Fraser illusion with phase-shifter Gabor patches. Popple et al., 1999.

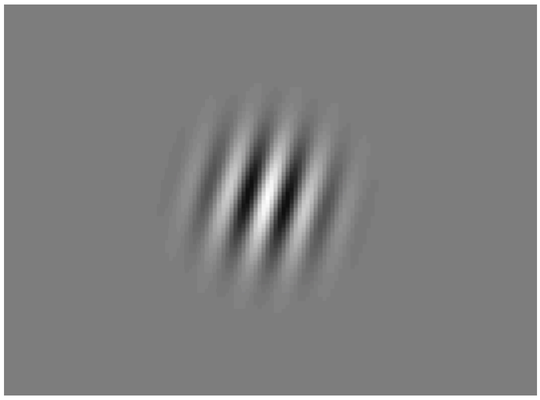

Fig. 2. A Gabor patch: a sinusoid convolved with a Gaussian, broadly used in simple cells experiments (e.g. orientation tuning, eliciting neural response with a strength depending on the orientation of the stimuli).

While the Fraser illusion leads to the conclusion that the local orientation of the elements influences the global orientation of the line, the collinear Gabor patches, being vertical, did not show any local tilt. However, by inducing a phase-shift along the patches, a certain global tilt is created, causing the 'Popple Illusions'. They form a set of optical illusions where phase-shifted elements, even though perfectly straightly vertical, produce tilted-looking lines, or circles not looking quite circular.

Ariella V. Popple studied these illusions – hence their name – and showed some results after varying their parameters and measuring the illusory tilt. The illusion at the core of this paper, having not been studied yet – or the study has not been publicly published – these results concern tilted-lines illusions.

As previously related in the literature (Popple et al., 2000) two parameters are of higher importance regarding the strength of this kind of illusion. First, the illusory tilt increases relative to the degree of phase shift separating the elements, a quarter cycles phase-shift producing the most enhanced illusion. Secondly, the number of patches influences the illusory tilt: the higher the number, the stronger the illusion. The separation between patches is also to be noted, their increase leading to a less perceived illusion. In a later paper, Popple et al. (2004) reformulated the list of parameters: the carrier orientation of each patch as well as the envelope's, and the phase shift were considered being the cues that could be manipulated. In our case, the carrier and the envelope follow the same orientation (circular shape, therefore same curvature) hence dismissing one of these parameters.

Those are the main parameters that build the illusory pattern; but let's take it to the next level. The Popple Illusion we used in this study (Fig. 3) adds up a curvature feature to the whole structure. Indeed, instead of dealing with straight lines that appear tilted, this paper relates the observation and analysis of a perfect circle that looks slightly squared, as our visual system tries to process each of its elements as well as its global shape at the same time. Indeed, simple cells in V1 fire when stimulated by black and white bars in a certain orientation and contrast polarity, and complex cells do the same but independently of the polarity. Second-order cues such as figure contour are being taken care of mostly by cells in V2, and some in V1.

This hierarchical processing, combined with the experiences from our natural environment, often make it hard to separately analyze different cues. Thus, the conscious result we got from our visual experience is an integration of all of them together, and when confronted with such illusion, we tend to have trouble observing the real shape instead of how it appears to be (Popple et al., 2004).

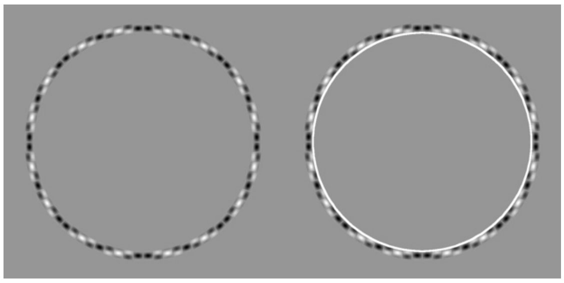

Fig. 3. The Popple Illusion studied in this paper. Left: a perfect circle made of Gabor patches, inducing a square-looking shape. Right: the exact same figure, but with a circle drawn on the inside, cancelling the illusion.

Methods [Jonathan]

Subjects

37 subjects participated in the experiment. All subjects had normal or corrected to normal visual acuity. All except two subjects had no prior experience in experiments related to perceptual vision. The subjects were between 22 and 62 years old.

Procedure

The subjects were presented ten variations of a circular Popple Illusion in a randomized order. For each variation, the subjects had to correct the illusion using a slider. When changed, the slider applied a distortion on the illusion as to revert the perceived error in the circle. The slider start- and endpoints were varied randomly to prevent correlation between the slider position and the correctness of the distortion. For each variation of the illusion the subjects rated, on a scale from one to five, how certain they were that they reverted the perceived error. All subjects had the illusions presented to them on the same monitor model with the same brightness, contrast and color settings.

Optical illusion and variations

The illusion variations are generated as gray scale images. They consist of a circular arrangement of Gabor Patches with a constant 1/6 sigma to lambda ratio, a stepwise increase in the phase shift between adjacent patches and rotated to be tangential to the arrangement circle. After each eighth of the circle the patches reverse the phase shift step. The variations are created by changing two variables; the number of patches around the circle, which ranged from 40 to 104 and the amount of phase shift between adjacent patches which was $\frac{8\pi}{number\ of\ patches}$ and $\frac{16\pi}{number\ of\ patches}$. The ten illusion variations represent all possible combinations of these two parameters. The number of patches is constrained to be numbers that are divisible by 8 so that the phase shift around the circle lines up at eighths of the circle circumference (Fig. 4)

Reverting the illusion and the correction factor

When the Gabor patches are arranged in a perfect circular fashion the perception of the arrangement is more akin to a square with rounded corners. To revert this perception, the radial placement of the Gabor patches – i.e. the distance from the center – is sinusoidally modulated around the circle. The frequency of this modulation cosine is 4 times that of the placement leading to a contraction of the radius at 45, 135, 225 and 315 degrees and a stretching at 0, 90, 180 and 270 degrees. The amplitude of the Modulation is described as $distortion * radius$. The distortion ranges from -0.1 to 0.1 corresponding to a ±10% radius modulation (Fig. 5). To make the overall

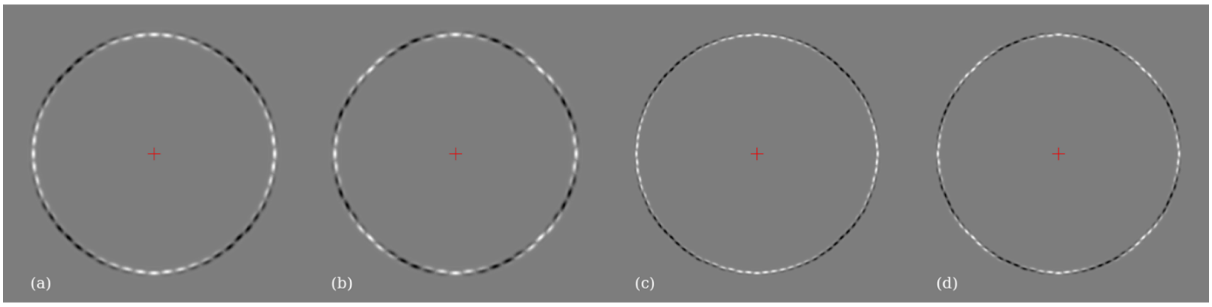

Fig. 4. Illusion Variations. (a) shift factor s=4, number of patches p=56, distortion d=0. (b) s=8, p=56, d=0 (c) s=4, p=88, d=0 (d) s=8, p=88, d=0

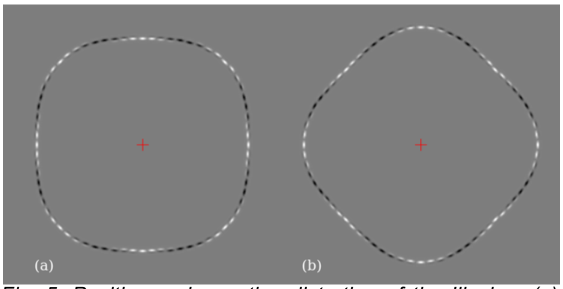

Fig. 5. Positive and negative distortion of the Illusion. (a) s=8, p=72, d=-0.05 (b) s=8, p=72, d=0.05

contour smoother, the patches are rotated slightly to match tangentially with the modulated circle.

Implementation

The Illusion generation is implemented in python3.7 and can be run using the command

(python(3)) bokeh serve ./src

in the project directory. It requires the Bokeh, Opencv, PIL and NumPy packages.

Data analysis and visualization was implemented in an IPython Notebook using the Pandas, Seaborn and Matplotlib packages.

Results [Raffael]

Analysis of Collected Data

In our experiment, the participants strongly believed that they had reversed the illusion (mean 4.69 out of 5) successfully.

To statistically verify this consensus among our subjects, we tested for a significant offset in distortion and checked for pairwise sample differences, assuming that each of the ten experiments is independent from another.

To allow for such a comparison, we verified visually that all our samples are gaussian distributed using a Q-Q plot in advance (Fig. 4). A Kolmogorov- Smirnov test applied category-wise confirmed these results (with $p < 0.01$) (Lilliefors, 1967).

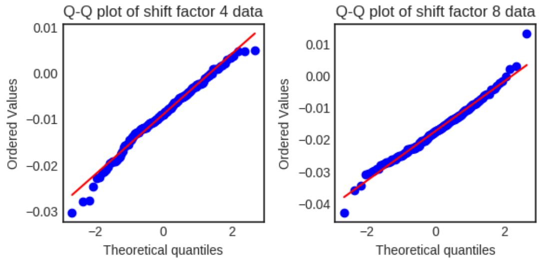

Fig. 4. Q-Q plots for shift-factors 4 and 8 confirm that our samples are normal distributed.

The close proximity to being normally distributed of our samples allows us to perform t-tests against the zero hypothesis: a slider value of 0.0 means no perturbation of the circle. From these tests, we can say that the corrections performed by the participants significantly deform the circle ($p < 0.05$) to the negative side, meaning the circle was bent inwards, making it less square-like.

We further proceeded to compare the hyperparameters (shift-factor and number of patches) of our experiment. In Fig. 5 pairwise comparison, we found that the number of patches negatively correlates with the correction factor. For higher patch numbers, the Gabor patch has less effect. We assume that this happens because the area of the individual patch decreases.

From a post-test examination of the experiment we concluded that the participants were most likely able to partially ignore the illusion by looking at the outer or inner border, as they converge towards a circular line with rather strong contrast against the background for large number of patches. Fig. 6 shows that we did not find a significant difference in this region.

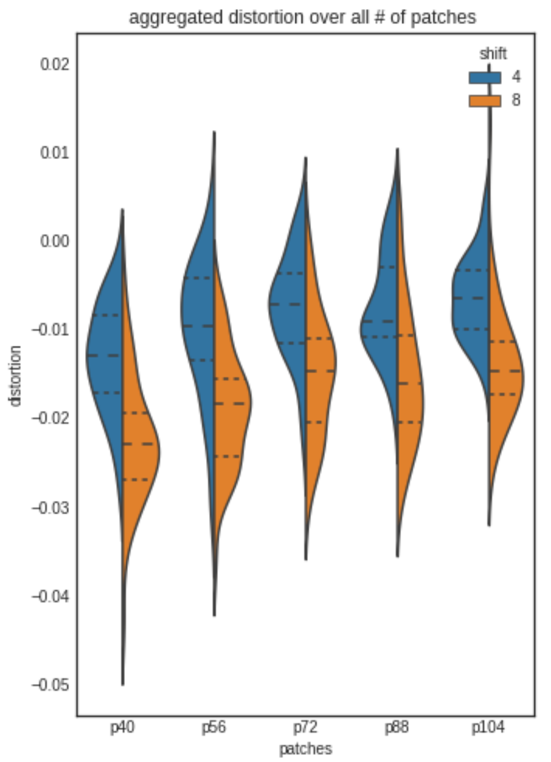

Fig. 5. An increase in distortion is clearly visible for low number of patches along the circle (p = {40, 56}). The effect is stronger for shift-factor 8. The shift-factor 8 dominance, measured by mean distance to 4, increases for p* = {40,56}.*

Fig. 6. The significance matrix shows the stagnation of the patch number hyperparameter: larger patch numbers do not show a significant change (red squares) in distortion.

As for the second parameter, the shift factor, which describes the rotation of the characteristic Gabor stripes around the patch center relative to the previous patch, we measured an increase in distortion for a larger shift factor (Fig. 7).

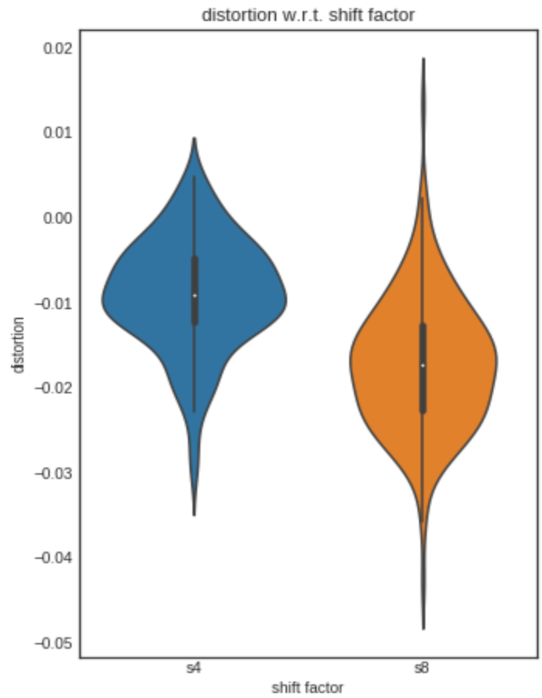

Fig. 7. Selected distortion with respect to the shift factor over every number of patches.

This seems to be evidence towards a local processing mechanism where the subject was tricked by the strong local rotation. A strong rotation in between two segments might be associated with a sharper angle that one would expect from a corner of the square-like shape, leading to a higher compensatory distortion. As seen in the first experiment, this effect is the strongest when the patches are large (meaning a small number of patches). This leads to the conclusion that our two hyperparameters depend on each other (Fig. 8).

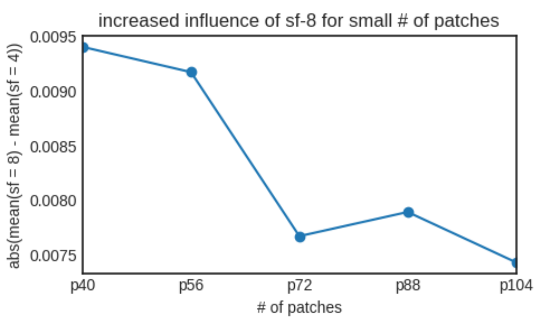

Fig. 8: We can measure a larger mean effect of shift factor 8 if the patch is bigger, implying some mutual information in between our hyperparameters.

Besides the distortion data, we recorded each participant's demographics (age, sex) as well as the use of visual impairments. Although due to the small sample size (n=37) we were not able to split the data in groups of meaningful size.

However, it is interesting to note that the average age was 24, the dominant sex was male (81%) and most users (76%) had no visual impairments.

Interpretation of Results

From all the geometric shapes, the circle is a very basic one that all our subjects were able to estimate very well. This result is supported by the large kurtosis in all our sample distributions which were also showing a mean that was close to 0.0, meaning the subjects were close to adjust for a perfect circle besides the influence of the illusion.

However, the Popple Illusion still manages to distract the participants in predictable ways. The larger the Gabor patch is, the stronger its effect on the participant. This could imply a bias introduced to pattern completion mechanism known from cell assembly theory, seen in the memory lecture. The more patches in the figure, the easier it would be to adjust towards the learned circular shape, by triggering more connecting cells that were strengthened in the past, as the representation in general gets closer to being a circle – in opposition to fuzzier figures made of less patches, where we assume that less, or worse, the wrong cells fire, that then might lead to the distortion.

We have strong evidence that the shift factor triggers local mechanisms that suggest an incorrect angular change when the participant followed the circle line visually, that was then corrected for. This effect also determines the predictable direction of adjustments, in our experiments meaning the distortion of the circle towards a star-like shape (negative distortion parameter).

Discussion [Jannis]

The results let us conclude that the two visual cues that we looked at: patch number e.g. patch size (1) and shift factor e.g. frequency of the Gabor filter (2) have a significant influence on the perception of the illusion. The fact that the illusion effect is bigger when the patch number (1) is lower and the frequency is higher (2) and by that the distance between the patch centers is bigger suggest a local mechanism as suggested in the paper of Popple & Levi (2004). These local orientation signals are perceived stronger by our visual cortex than the global orientation e.g. circular alignment cues. To further examine the local effect on the gravity of the illusion, one could use an eye tracking device to see if the participant follows the line or looks at the hole illusion to make judgements about the seen image.

In the future the experiment could be extended with more variations. It would be interesting to know what happens if less patches would be used or if the shift factor is higher. We expect that the illusion will stop working at a certain variation.

Acknowledgment

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Task Matrix

Task	Marina	Jonathan	Raffael	Jannis
Programming		X	X	
Data Science	X		X	X
Literature Review	X			
Presentations		X		
Report	X	X	X	X