UNIVERSITÀ DEGLI STUDI DI PADOVA

Dipartimento di Psicologia Generale

Corso di laurea in Scienze Psicologiche Cognitive e Psicobiologiche

Elaborato finale

The Honeycomb illusion: Peripheral vision of contours, unlike that of objects, is refractory to predictions, extrapolation and memory effects

Relatore
Prof. Marco Bertamini

Correlatrice
Dott.ssa Carolina Maria Oletto

Laureanda:
Marica Zulianello

Matricola:
2017573

Anno Accademico 2022-2023

Abstract

In the Honeycomb (HC) illusion, a uniform pattern is not perceived as such, with a visible change from the center to the periphery of the visual field (Bertamini et al., 2016). This illusion does not follow expectations and predictive perception.

In this work, we specifically investigate the effects of Inattentional Blindness and Extrapolation in the HC illusion, through a series of two pairs of experiments. In the first pair, we test participants' ability to detect stimuli in two different conditions. In the illusion condition, the lines overlap with the intersections of the grid, while in the control condition, they do not. Lines could tilt left or right. In the second pair of experiments, we investigate participants' ability to discriminate these stimuli, by introducing an additional central region of varying size filled with crosses and asking them the orientation of the peripheral lines. Each experiment also had a variation with an additional foveal task to test the Inattentional Blindness phenomenon.

Results of the first pair of experiments show that participants are able to detect stimuli only up to 13.44±0.24 degrees in the illusion compared to 49.23±0.21 degrees in the control condition. However, the size of the region reported as filled with stimuli decreases significantly more in the control condition when introducing the foveal task. This suggests that the HC illusion is less subject to Inattentional Blindness. In the second pair, the difference between the mean dprimes in the illusion versus the control condition remains the same whether there is the additional foveal task or not (approximately 0.6 in both cases). There is however a significant interaction effect between the addition of the foveal task, the condition and the size of the central region of degrees, further suggesting that the Honeycomb illusion responds differently to Inattentional Blindness compared to uniformly perceived patterns. Finally, a comparison between the two experiments shows that the size of the region in which participants are able to detect stimuli corresponds to the one in which they can discriminate them in the illusion condition, while it is significantly larger in the control condition. This indicates that the HC illusion is less prone to Extrapolation, thus proposing a more genuine vision.

Attention modulated the responses, without changing the basic differences. A fundamental difference in the perception of contours in central and peripheral vision is refractory to expectations.

Contents

1 Introduction

Although the differences between peripheral and foveal vision are well known, it is impossible for us to be aware of them since our subjective experience of vision is uniform and stable. Research suggests that our visual system does not perceive the world in a photographic manner but applies simplifications through biases. There are many errors and fallacies in our visual system: Visual Memory, Change Blindness, Multiple Object Tracking, Attentional Blink, (Haberman and Whitney, 2012). The visual system employs simplifications through heuristics that have been learned over time from the experience of everything that is predictable and stable. In other words, the visual system leverages the statistical regularities of the world to simplify information. In this context, the study of optical illusions is particularly relevant insofar as they propose visual stimuli different from ecological ones, thus tricking the visual system and failing to follow well-known mechanisms. The Honeycomb (HC) illusion, presented by Bertamini et al. (2016) is precisely an example of such an optical illusion, in which certain visual mechanisms seem not to work as expected. In this work, we present a series of experiments with the goal of analyzing two such mechanisms: Inattentional Blindness (Mack and Rock, 1998) and Extrapolation (Stewart et al., 2020).

1.1 The Honeycomb Illusion

The HC Illusion is a failure of the visual system to see a uniform pattern as it is. The mechanisms underlying this phenomenon do not follow the basic rules of vision. In this optical illusion, we see the pattern as it is in the centre of our visual field (fovea), but in the periphery the lines disappear, leading to think that they are actually only present in the centre, when they are actually present all over the texture. This suggests a failure of the mechanism of Extrapolation, since the complexity in the periphery is not simplified by our brain assuming the uniformity of the pattern, as it happens in other illusions such as the healing grid (Bertamini et al., 2016, p. 8), and in non-illusion textures. This leads us to think that the mechanisms under this illusion are entirely different. The original HC illusion is formed by a grid of hexagons with superimposed lines at the grid's intersections, as shown in Figure 1. Both the grid and the lines are perceived while separate, but if they are shown together, the perception of uniformity disappears. That is, the reason could not be related to the distance of the features from fixation. As is shown in Bertamini et al. (2019), who quantified through a quasi-experimental procedure the illusion, people reported seeing lines in circa eight hexagons around fixation.

Even when the observer could navigate through the pattern, the perception did not change. Changing fixation points and fixating more sections of the pattern do not help the perception or change it. Also, time does not play any role since the reports were not modified if the fixation lasted more or less time.

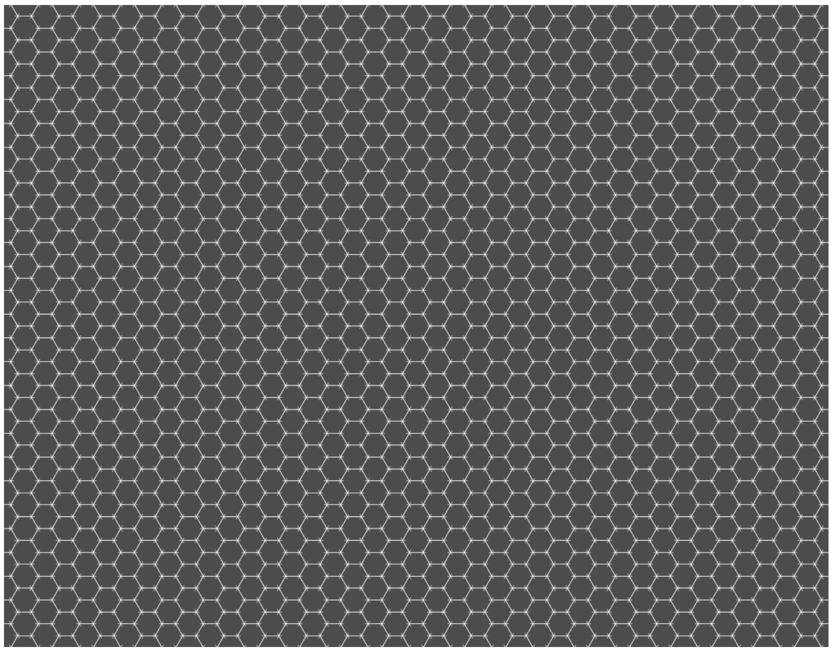


Figure 1: The original HC illusion introduced by Bertamini et al. (2016).

The importance of knowing how an illusion works leads to also knowing its limits. In order for the illusion to work, the size of the pattern must cover most of the visual field. The key point is the interaction between hexagons and lines. If the components are not superimposed, or if the lines are not precisely on the intersections of the grid (e.g., placed in the middle of the sides of the hexagons, see Figure 2) the illusion disappears. In addition, the colour of the elements is essential for the illusion to work: if the lines and the grid have different colours, especially with strongly contrasting colours, the illusion disappears as well (see Figure 3). Hence, the elements have to be the same or low contrast colours, in order to have strong illusion effects.

1.2 Experiments

In this work, we report and discuss the results of two pairs of experiments. The first pair investigates participants' ability to detect stimuli in the HC illusion compared to a control

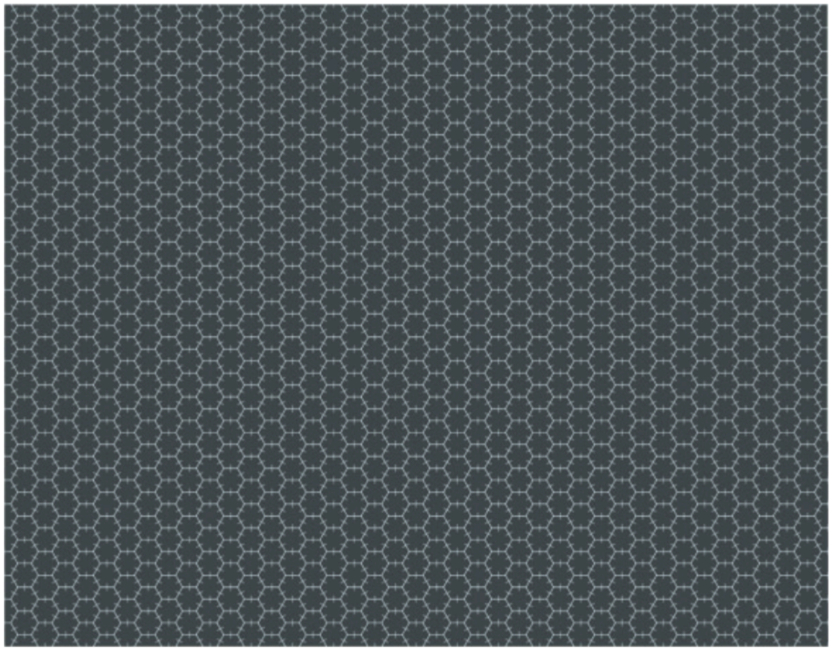


Figure 2: The original HC illusion where the stimuli lines are not placed on the intersections of the grid. The illusion fails in this case.

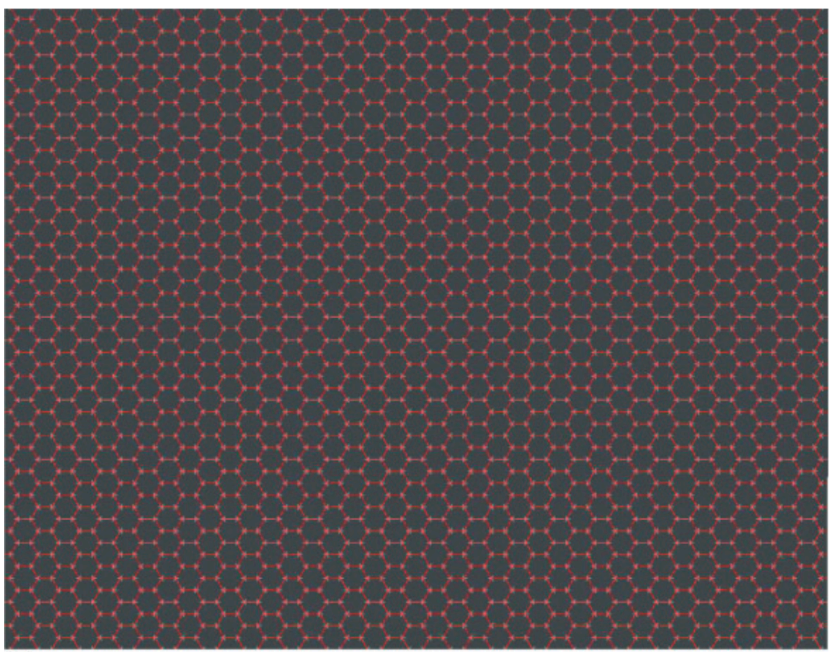


Figure 3: The original HC illusion where the stimuli lines and the grid have contrasting colors. The illusion fails in this case.

condition. In the baseline experiment, which we call Uniform, participants are asked to report how much of the screen is filled with stimuli (lines), through a 3-Alternative Forced Choice (3AFC). In its variation, we introduce an additional foveal task, in which participants have to discriminate which of the arms of the fixation cross is longer. In the second pair of experiments, we substitute the lines in the centre with a central region of varying size filled with crosses. Participants are asked to discriminate the orientation of the lines. As in the first pair of experiments, we have a base version, Blindsight, and a variation with the same additional foveal task.

In the next section, we introduce the relevant literature and subsequently justify how these four experiments help us better understand how visual mechanisms behave under the HC illusion.

2 Relevant work

Our vision is built on a variety of mechanisms. To give more context to the reader, we propose here a brief overview of the main theories relevant to the study of optical illusions. We then present prominent examples of such illusions, discussing them in relation to the theories outlined, and conclude by illustrating the HC illusion, the main focus of this thesis, in the context of this research field.

2.1 Important theories of visual perception

2.1.1 Foveal vs Peripheral vision

Already at the level of the retina, rods and cones are not equally distributed in the fovea with respect to the periphery. With a higher concentration of cones in the fovea, the human eye achieves a higher visual accuracy thanks to the higher amount of light received and the cones' smaller receptive fields. On the contrary, the larger rods majorly present in the periphery allow us to expand our visual field and catch movement faster at the cost of accuracy. Such an unequal distribution of rods and cones in the human eye provides us with both a precise yet narrow foveal vision and a larger yet fuzzier peripheral vision. This leads to the fact that our vision is not like a camera.

2.1.2 Extrapolation

With Extrapolation, researchers refer to the phenomenon according to which participants tend to extrapolate visual information in the periphery of their visual field with information from their central vision. This happens because peripheral vision is less precise than the foveal one and thus the brain tends to utilise the better information it has to reconstruct a precise image (although potentially false or misleading). This mechanism works because our environment is usually uniform, so this bias is not totally wrong and it works well in the majority of ecological situations (Stewart et al., 2020).

2.1.3 Uniformity Assumption

The Uniformity Assumption refers to the idea that the visual field should appear uniform and consistent to an observer. This means that objects and surfaces should have a consistent appearance in terms of colour, brightness, and texture. The Uniformity Assumption is important because it allows us to perceive the world as stable and coherent. It helps us make sense of our visual environment and recognize objects and patterns. When the Uniformity Assumption is violated, as well as all the other biases and mechanisms, it can lead to perceptual illusions or distortions.

2.1.4 Visual Memory

When observing something, we shift our gaze, both voluntarily and not. Yet we are perfectly capable of remembering what we have just seen (even in the case of saccadic movements, for which we do not even realise what we are doing) and combine the different views obtained to construct a more complete mental image.

2.1.5 Inattentional Blindness

Multiple studies have demonstrated that, contrary to previous beliefs, the human eye does not merely act as a camera, always active and ominous, but is instead subject to the person's attention. Inattentional Blindness thus refers to the inability to perceive prominently observable objects even when they are being directly observed, due to the dispersion of our attention to other focal points (Mack and Rock, 1998).

2.1.6 Filling-in mechanism

Our brain automatically operates a mechanism called filling-in which covers the natural scotoma we all have in our retina with the information around it, without us noticing it. This works even with scotoma obtained by injuries.

2.1.7 Change Blindness

Due to a lack of representation of the world, people can fail to notice changes, even if they are big. This information can lead researchers to think that our mental construction of the world is poor, little as needed to not notice changes if they occur, as studied by Simons et al. (2000).

2.1.8 Grand Illusion Hypothesis

The Grand Illusion Hypothesis is described by Cohen (2002). It combines two important illusions: Change Blindness (Simons et al., 2000) and Inattentional Blindness (Mack and Rock, 1998). This grand illusion leads to the fact that people think they have an over-detailed image in their head of the word, or at least a quite confident idea. Furthermore, our experience of the word is not a group of consecutive photos but there is fluidity in what we see in spite of the saccades. To move further, people are also firmly convinced that what they see corresponds exactly to how the word is.

2.2 Optical illusions as research tools to study visual mechanisms

Studying these phenomena is central to the research in visual perception, so that we can better understand how we see and perceive the world. To do so, researchers have been developing and using a large variety of optical illusions, with the reason that certain mechanisms for visual perception in an ecological situation fail when seeing optical illusions. It is thus essential to study these illusions to question what we assume about visual perception and to better understand visual perception mechanisms.

2.2.1 Hermann Grid

The fascinating work about the Hermann Grid (Hermann, 1870) presents an illusion in which non-existing stimuli are perceived far from fixation, caused by the mechanism called lateral inhibition (Cook and McReynolds, 1998). The illusion employs colour contrast of its alleys and squares components. The Hermann Grid illusion creates dots in the periphery because of peripheral larger field receptors. The peculiar interaction between the alleys and the squares creates a special activation in the receptive field that leads to lateral inhibition. The original Hermann grid illusion is characterised by light spots perceived at the intersections of a dark grid on a white background. attributed this illusion to the differential stimulation of ON-or OFF centre receptive fields.

2.2.2 Scintillating Hermann Grid

Studies show that a blurred Hermann Grid creates an illusion of scintillation (Schrauf et al., 1997). Bergen et al. (1985) modified the standard Hermann grid by low-pass filtering, creating a blurred grid as a variation of the Hermann Grid, in which intersections were brighter than the bars. During eye saccades, dark patches appear at those intersections. When introducing superimposed small uniform disks at the intersection of the HG to cancel the illusory grey spots, scintillating dark spots appear within the white disks and similarly scintillating light spots appear within the black disks.

2.2.3 Healing Grid

In the Healing grid, peripheral and foveal patterns are different, resulting in a non-uniform texture. The central part of the pattern is composed of a grid of squares while in the periphery the grid gradually breaks apart. For the illusion to occur, it is necessary to fixate the centre for a minimum time. After a certain time of fixation, the pattern appear to become uniform, to "heal" itself. The central regular grid gradually expands in the periphery giving the idea that the grid is slowly healing, hence the name of this illusion. According to Kanai[1], this phenomenon is caused by the ‘‘preference of the visual brain to see regular patterns’’ (Bertamini et al., 2016, p. 8).

2.2.4 Extinction illusion

The Extinction illusion of Ninio and Stevens (2000) is a variation of the scintillating Hermann grid. By reducing the size of the white disks in the scintillating grid and outlining them in black, they seem to partially disappear with "only a few clustered elements simultaneously visible, the grey alleys being otherwise completed by a kind of filling-in." (Ninio and Stevens, 2000, p. 1213).

2.3 Placing the Honeycomb illusion in context

Recently, a novel optical illusion has been proposed, the HC illusion (Bertamini et al., 2016). This illusion is interesting as it differs from the other well-known examples discussed. For instance, the HG and the HC illusion (HC) do not follow the same rules since in the HG the effect of the illusion is to see elements that do not exist in the periphery while in the HC the effect is precisely the opposite: not seeing elements that are in the periphery. For this reason, HG and HC probably do not follow the same visual mechanism, that is lateral inhibition. The same differences apply for the Scintillating Hermann Grid, as well as the need for rapid stimuli since their presentation must be short (Schrauf et al., 1997, p. 4) while the HC illusion does not change over time. Most illusions, such as the healing grid, show that the foveal vision takes over the peripheral one, since it's more detailed and accessible. On the contrary, these

[1] Winner of the Best Illusion of the Year contest in 2005, http://illusionoftheyear.com/2005/08/healing-grid/

illusions show the periphery has its own rules and does not only follow the fovea. Finally, the Healing Grid is based on adaptation and Extrapolation and can therefore be said to be opposite to the HC. Extinction illusion (EX) is similar to HC for several aspects, such as the fact that both illusions rely on elements of a pattern not perceived in the periphery but not because of eccentricity. Both illusions highlight that there are independent mechanisms in the periphery. There is a dissociation between HC and EX in terms of contrast polarity (white lines/dots on a black grid or vice versa). This suggests that the two illusions depend on contrast polarity in different and complex ways influenced by the spatial relationship of features and texture ”contrast polarity” (Bertamini et al., 2019, p. 15). HC becomes weaker when its components have a strong contrast polarity (3); on the contrary EX needs contrast polarity to work.

As highlighted before, the HC, like other optical illusions, can serve as a powerful tool to investigate specific visual mechanisms. In particular the HC is helpful to study Extrapolation, the Uniformity Assumption, Visual Memory and Inattentional Blindness, among the ones discussed above. Some of these effects have already been discussed (Bertamini et al., 2016). To further this research, in this thesis, we specifically investigate the phenomena of Extrapolation and Inattentional Blindness, through a series of four experiments. The table 1 summarizes the main visual mechanisms related to the HC illusion, presenting what has already been studied and what this work aims to better understand. In the next section, we present the main hypotheses of this work and describe the four experiments.

Table 1: Effect of relevant visual mechanisms on the HC illusion

Mechanism	Brief description	Effect in HC illusion
Extrapolation	We rely on what we see in the central region to fill in the gaps in the peripheral vision.	We want to test whether what participants report to be able to detect corresponds to what they are able to discriminate. We expect there will not be Extrapolation in the illusion condition, as put forward by Bertamini et al. (2016, p. 12).
Uniformity Assumption	We perceive the world as stable and coherent through statistical vision.	No (Bertamini et al., 2016, p. 12)
Memory	We move our gaze and combine different views to create a more complete mental image of what we see.	No (Bertamini et al., 2016, p. 4).
Inattentional Blindness	The dispersion of the attention can lead to not perceiving stimuli on the visual field.	We want to test whether participants' discriminative accuracy lowers when introducing an additional foveal task.

3 Methods

3.1 Hypotheses

As just discussed, optical illusions have been widely studied to investigate various visual mechanisms. In this thesis, we tackle the HC illusion through the lens of two well-known visual mechanisms: Inattentional Blindness and Extrapolation, that we presented earlier. We put forward the following two hypotheses:

H1 : By introducing a foveal task, we expect participants' performance to lower, due to the Inattentional Blindness phenomenon (Mack and Rock, 1998)

H2 : We expect that in the control situation, in which the uniform pattern is perceived as it is, there is Extrapolation, while in the HC illusion, there are two possibilities: either what the participants report to see coincide with what they are able to discriminate or they see more than they can discriminate

To test these two hypotheses, we propose four experiments, grouped in two pairs. The first pair deals with the issue of detecting stimuli, while the second investigates the ability to discriminate them. In each pair, the second experiment is a variation of the first, in which we introduce a foveal task to test the effect of Inattentional Blindness (H1). Furthermore, comparing the two pairs of experiments (detection and discrimination) allows us to explore the effect of Extrapolation (H2). On one hand, we know how far can people see things in both baseline and foveal tasks; on the other hand, we know how far they can discriminate between what they see. We expect that when the lines are not depicted at the intersection of the grid (the control condition), there is Extrapolation so detection and discrimination tasks could generate different results. Instead, in the HC situation two scenarios are likely: either what the participants report to see coincides with what they are able to discriminate or, as in the control situation, they see more than they can discriminate.

3.2 Stimuli and apparatus

Participants were presented with a series of stimuli, consisting of oriented lines (right or left, Figure 4 and Figure 5) embedded in a squared grid. The stimuli were presented for 250 ms, with two possible conditions: in the illusion condition, the oriented lines are placed at the intersection of the grid (figure 4), while in the control condition they are placed at the centre of the grid squares (figures 5).

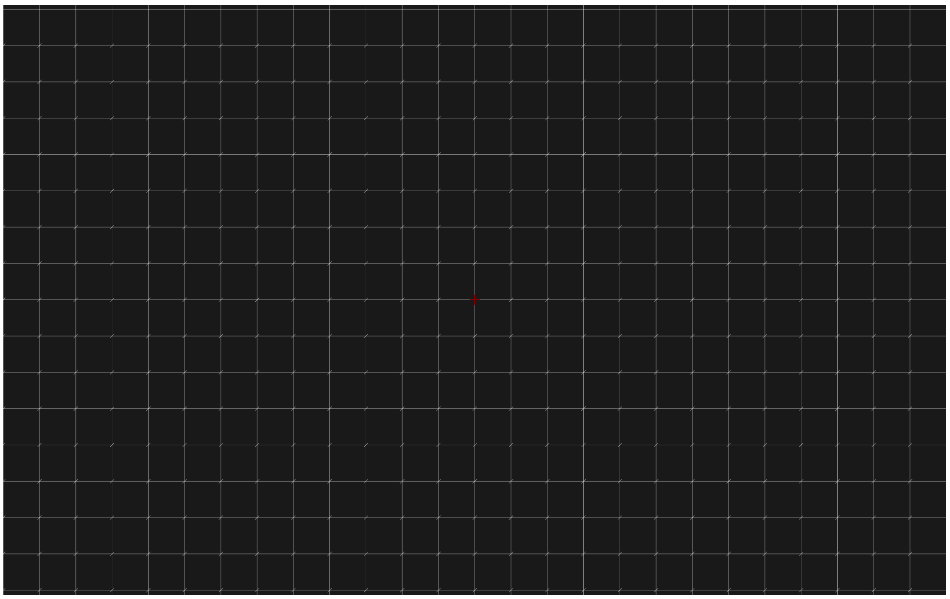


Figure 4: Stimuli image for the illusion condition, where the lines are placed at the intersections of the grid.

A red fixation cross was always present. The grid could be aligned to the red fixation cross (Figure 6a) or not (Figure 6b). Participants' eye movements were monitored with an eye tracker (Gazepoint GP3). All the images were generated using Python and PsychoPy (Peirce, 2007) and displayed on an EIZO monitor (52.8 x 29.7 cm). A chinrest was used to fix the distance from the screen at 57 cm. The squares in the grid always had a side of 2 cm. All the lines and grids were white on a dark grey background.

3.3 Experiment Uniform and its Foveal variation

As said, the first pair of experiments in whether the introduction of a foveal task, and so divided attention, can change the perception of a uniform pattern. This hypothesis is based on the fact that attention and perception are correlated. We do not perceive things, mostly consciously, when we don't put our attention to them. Such as driving the same road every day probably leads to forgetting the trip just done, or simply people blink all the time but rarely realise when they do it. The very first experiment, which we call Uniform, is built in

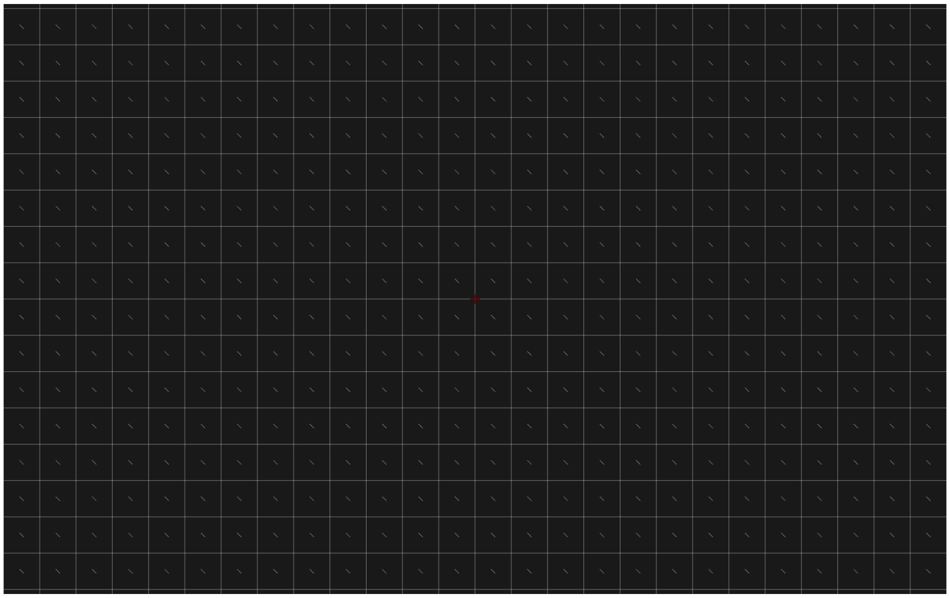


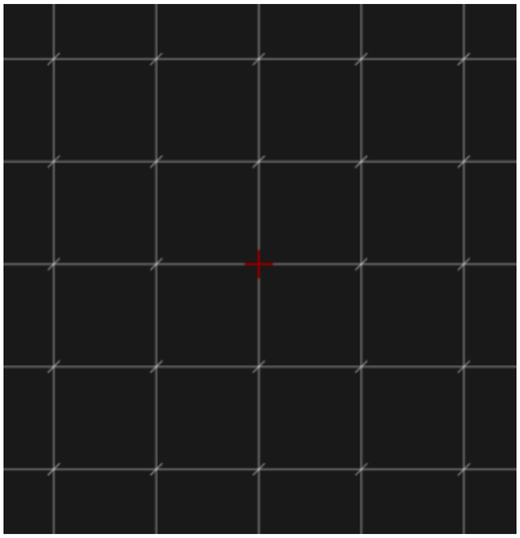
Figure 5: Stimuli image for the control condition, where the lines are not placed at the intersections of the grid, but in the centre of the squares.

order to study the HC illusion, or even study how people perceive the illusion compared with the control situation. participants had to report how big the region was in which they could see the lines. We expect, as studied in Bertamini et al. (2016), that people will report seeing a smaller portion of the screen populated with lines in the illusion than in the control situation.

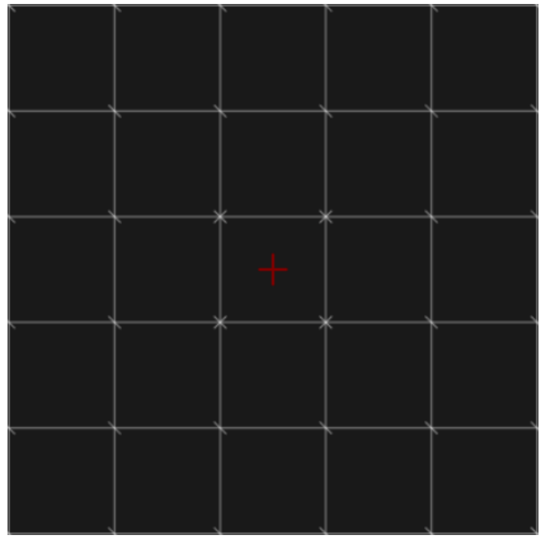
3.3.1 Uniform

In this experiment, to answer how big the region with stimuli was, participants had a 3AFC: central region, half or whole screen, corresponding to 6, 24 and 52 degrees of the screen. Even if the responses are discrete, we consider them as an approximation of the subjective report so we treat the data as continuous. During practice, the lines specifying the response options were visible (Figure 7). participants had 32 practice trials with visible lines of the response region. After practice, their responses over 320 experimental trials were recorded, without the guide lines.

Twelve participants took part in this experiment (age range: 19 - 55, 9 female, 1 left-handed). All had normal or corrected vision.



(a) Grid aligned



(b) Grid not aligned

Figure 6: The grid can be aligned or not with the central fixation cross.

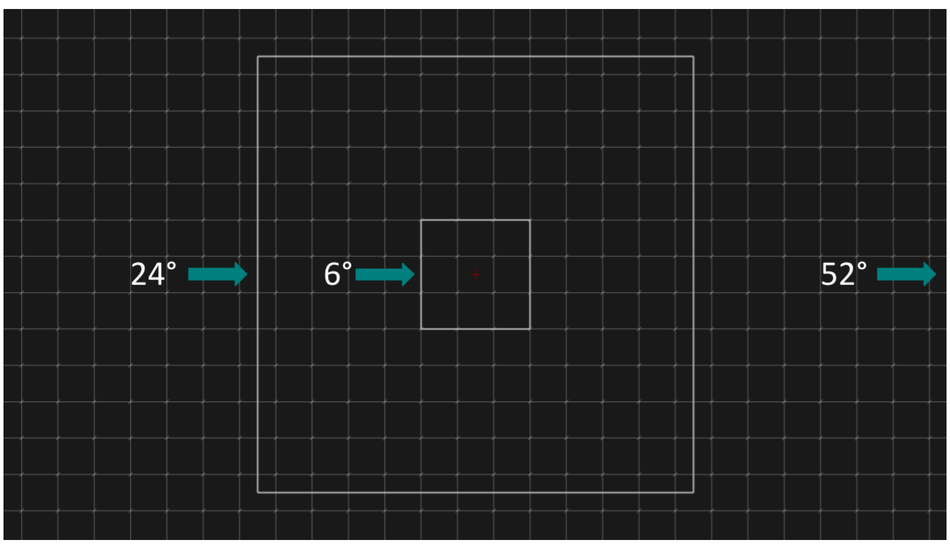
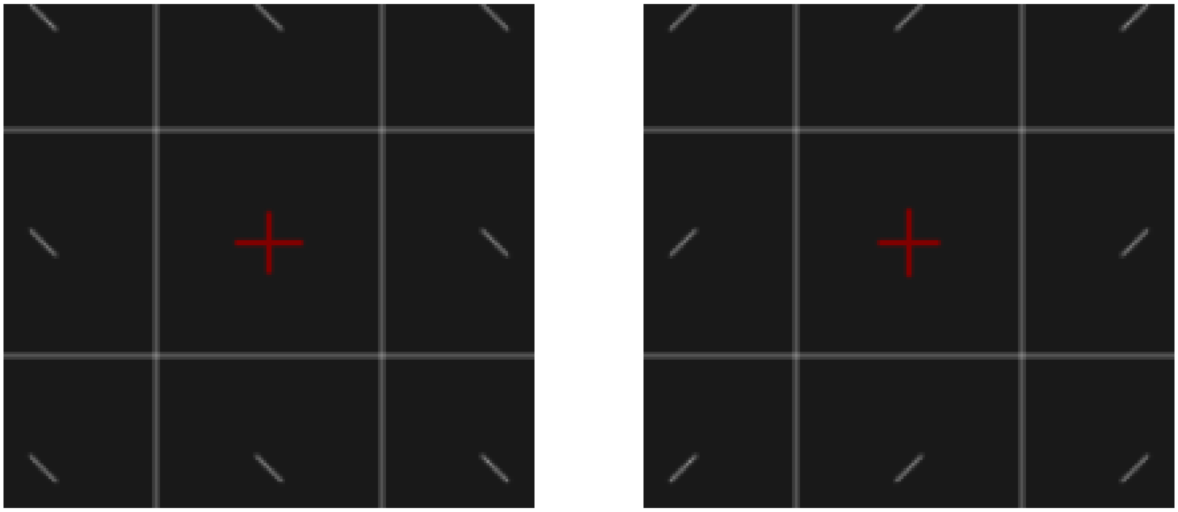


Figure 7: Practice lines shown during the practice trials for the 3AFC of the Uniform experiment.

3.3.2 Uniform with Foveal variation

The second experiment, which we call Uniform foveal variation, is built just like the first but with the introduction of a foveal task while simultaneously answering the same 3AFC of the "main" task. So, due to divided attention and Inattentional Blindness studied Mack and Rock



(a) The horizontal arm is longer. (b) The vertical arm is longer.

Figure 8: Discriminative foveal task: participants have to report which of the fixation cross arms is longer

(1998), we expect that the foveal task introduced in the second experiment will decrease the capacity of the participant to perceive the uniform pattern as wide as in the Uniform. Finally, since memory and attention fail on the HC illusion, we do not expect a decrease in performance in the illusion situation of the Uniform foveal variation.

For the foveal task, participants had to discriminate which arm of the fixation cross was longer (Figure 8). They had 128 practice trials in which they received auditory feedback for the foveal task and then 320 experimental trials.

Twelve participants took part in this experiment (age range: 19 - 31, 7 female, 1 left-handed). All had normal or corrected vision.

3.4 Experiment Blindsight and its Foveal variation

The second pair of experiments, which we refer to as Blindsight, serves to test participants' ability to discriminate the stimuli, rather than simply detecting them.

3.4.1 Blindsight

In this experiment, we introduced a central region of crosses, with eight different sizes (from 4 to 18 degrees), that appear around the fixation point (see Figure 9). In this case, participants were asked whether the lines either on top of the grid intersections, illusion condition or at the centre of the grid squares, control condition, were oriented left or right, through a 2AFC. Their accuracies were measured with d', where d' = 0 corresponds to 50% (chance) while d' > 4 corresponds to around 100% accuracy. Since the task is objective, we consider the sensitivity of the participant to detect the correct stimuli using the mean of every participant's dprimes. Obviously the wider the central region of crosses is, the harder the discrimination task is. So, as a result of these experiments, we can establish how far from fixation people can discriminate correctly about what they see, either in the illusion or the control situations. Participants had 32 practice trials followed by 160 experimental trials.

Twelve participants took part in this experiment (age range: 18 - 56, 9 female, 1 left-handed). All had normal or corrected vision.

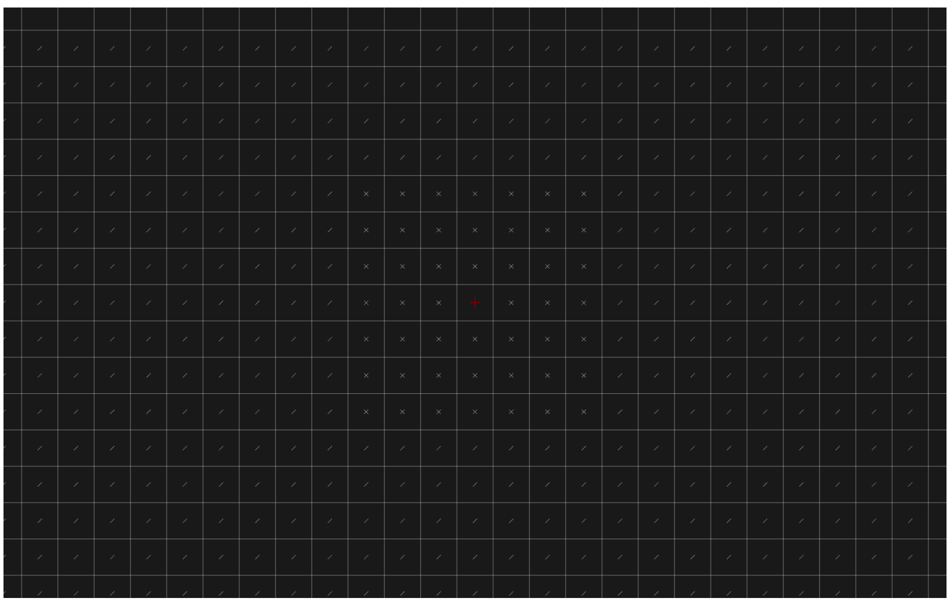


Figure 9: Stimuli image with a central region of crosses for the Blindsight experiment.

3.4.2 Blindsight with Foveal variation

Finally, as in the first pair, we introduced an additional task with the same foveal one. We expect participants' accuracies to decrease with wider central regions of crosses. Through this experiment we can quantify the visual angle in which participants are able to discriminate what they are perceiving. If there is a point in which the accuracy of the participants decreases near d'=0, it will mean that they are not able to perceive the stimuli anymore, but only crosses. So we can quantify the visual angle in which people can perceive uniform patterns and the HC illusion. We expect the lowest performance in the HC situation with foveal variation. The participants had 64 practice trials in which they received auditory feedback for both orientation of the lines and foveal task and then 320 experimental trials.

Twelve participants took part in this experiment (age range: 21 - 27, 6 female, 1 left-handed). All had normal or corrected vision.

In Table 2 we summarize the main goals of the four experiments.

Table 2: Summary of the main goals of the four experiments presented in this thesis.

Uniform	HC condition is less detectable than control condition
Uniform with foveal task	Same trend as the baseline but lower in detectability due to the foveal task, mostly for control condition
Blindsight	Discrimination better for control but lower than the detectability on the Uniform, HC condition better/ worse detectability as baseline
Blindsight with foveal task	Same trend but lower in discriminate what they are able to detect due to the foveal task, mostly for control condition

4 Results

4.1 Uniform and its Foveal variation

In the Uniform experiments, we investigate how far participants are able to detect stimuli while fixating the centre of the screen. Their responses are recorded through a 3AFC and thus are technically discrete but we processed them as continuous, calculating the mean of the responses for each condition. In the illusion, participants' median of the responses is 6 degrees and the mean is 13.44±0.24 degrees, while in the control condition, the median is 52 degrees and the mean 49.23±0.21 degrees. By inspecting the detailed responses in Figure 10, we observe that responses in the illusion case are mostly spread across the first two sizes (6 and 24 degrees), for a total of 97.8% responses, while in the control condition there is a much higher agreement with 91.25% responses at 52 degrees. We check these results with a one-way ANOVA test, comparing the means of the responses in the illusion versus the control conditions. We obtain a significant difference: $F(1, 11) = 1015, p < 0.001$.

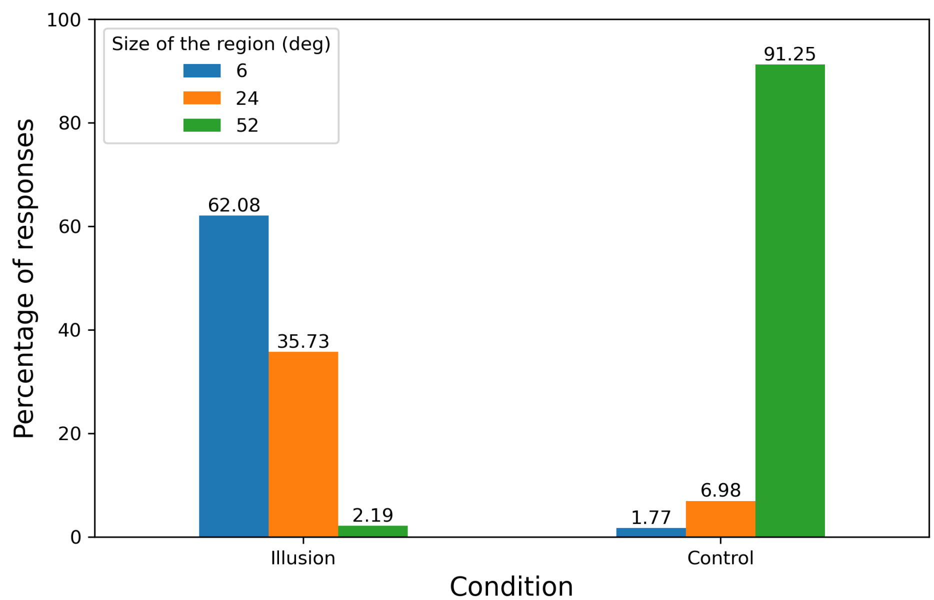


Figure 10: Percentages of responses in the Uniform experiment for the size of the region reported as filled with stimuli, in the illusion and the control conditions.

In the variation of the first experiment, we introduce an additional foveal task in the form of a discriminative foveal task, to test the effect of Inattentional Blindness. As in the baseline version, we treat participants' responses are continuous, reporting medians and means. In the illusion condition, we obtain a median of 6 degrees and a mean of 11.74±0.28 degrees, while in the control we observe a median of 52 and a mean of 37.30±0.41. This time, in the illusion participants reach more of a consensus, with nearly 80% of the responses at 6 degrees, while in the control condition, there is more spread, with only 57.08% answers at 52 and 28.02% at 24 degrees, as reported in Figure 11. As before, results are tested with Satterthwaite's one-way ANOVA, finding the difference in the means between the two conditions significant ($F(1, 11) = 104, p < 0.001$).

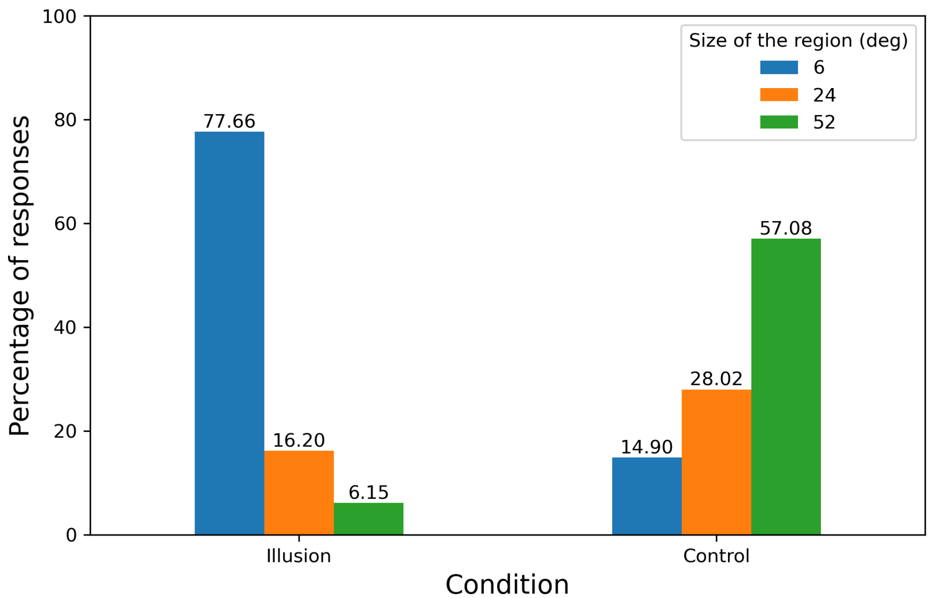


Figure 11: Percentages of responses in the Uniform experiment with Foveal variation for the size of the region reported as filled with stimuli, in the illusion and the control conditions.

Furthermore, the effect of the addition of the foveal task is found significant ($F(1, 22) = 9.91, p < 0.01$) and the ANOVA test reveals a significant interaction effect between the introduction of the foveal task and the two conditions of the experiment ($F(1, 22) = 13.93, p < 0.01$).

4.2 Blindsight and its Foveal variation

In the Blindsight experiment, we investigate how far from fixation participants are able to discriminate (rather than simply detecting) in the illusion and the control conditions. In order to achieve this, a central region filled with crosses is introduced in the stimuli images, with varying sizes from 4 to 18 degrees. We measure participants' accuracies in discriminating the lines orientations with dprime. Figure 12 presents the change in mean dprimes with the size of the central region of crosses, both in the illusion and control conditions. In the first case, mean dprime starts around 3.5 at 4 degrees and falls to 0 around 14 to 16 degrees, while in latter, it starts over 4 and falls to 0 towards 18 degrees. Across all central region sizes, we observe a mean dprime of 1.13±0.17 in the illusion and 1.73±0.20 in the control condition. We test these results with a two-way ANOVA, investigating the effect of the size of the central region of crosses and of the condition (illusion or control) on the participants' dprimes. Both effects are significant ($F(1,177) = 221.96, p < 0.001$ for the first, $F(1,177) = 13.11, p < 0.001$ for the second) as well as the interaction of these effects ($F(1,117) = 5.67, p < 0.05$).

As for the first pair of experiments, we introduced an additional foveal task in the form of a discriminative foveal task to test the effect of Inattentional Blindness in the Blindsight experiment. Figure 12 presents the variation of participants' mean dprimes for the different sizes of the central region of crosses, showing that, in this case, in the illusion condition dprime starts at 2 at 4 degrees and fall towards 0 around 10 to 12 degrees. In the control, it starts around 3.5 and falls to 0 at 12 degrees. As expected, participants' accuracies are lower than in the baseline version of the Blindsight experiment, with means across the sizes of the central region of crosses at 0.39±0.11 in the illusion and 1.05±0.18 in the control condition. A two-way ANOVA is employed again to test the effect of the size of the central region of crosses and of the condition on the participants' dprimes, finding both effects significance ($F(1,177) = 181.9, p < 0.001$ for the first, $F(1,177) = 52.7, p < 0.001$ for the second) as well as their interaction ($F(1,177) = 35.3, p < 0.001$).

Statistical analysis with a three-way ANOVA to compare the Blindsight experiment with its Foveal variation verifies that the effect of the foveal task is significative ($F(1,22) = 6.97, p < 0.05$), as well as the effect of condition ($F(1,22) = 35.02, p < 0.001$) and size of the central region of crosses ($F(1,22) = 173.55, p < 0.001$). We do not find a significant interaction effect of the addition of the foveal task with the condition ($F(1,22) = 0.16, p = 0.69$), or with the size of the central region of crosses ($F(1,22) = 1.48, p = 0.24$). The interaction between all three of these factors (addition of the foveal task, condition and size of the central region of crosses) is however found to be significant ($F(1,22) = 4.49, p < 0.05$).

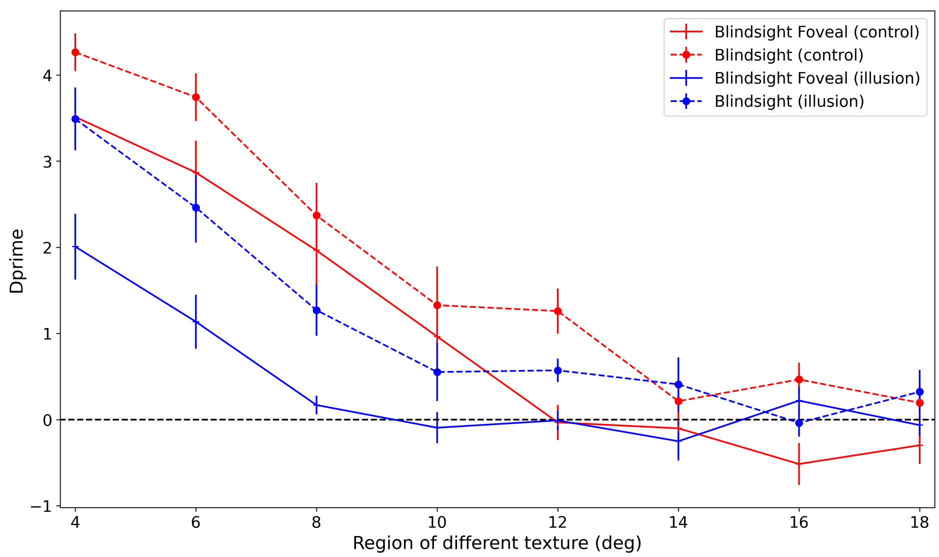


Figure 12: Participants' accuracies reported with dprimes in their ability to discriminate stimuli lines orientation. Results are reported both for the Blindsight experiment (dashed lines) and its Foveal variation (filled lines), and for both conditions (illusion in blue, control in red). Error bars are SE of the mean.

5 Discussion

5.1 Uniform experiment and effect of the foveal task

As previously demonstrated in Bertamini et al. (2016), the HC illusion does not need adaptation. The Uniform experiment verifies this claim, since even while showing the stimuli for only 250 ms to the participants, there is still a strong illusion effect. In the control condition, participants detected everything or almost everything that appeared on the screen (mean of 49.23±0.21 degrees, out of a maximum of 52), the stimuli were clearly visible and the participants reported it with high confidence. In the illusion condition the detection is narrower (mean of 13.44±0.24 degrees, see Table 3), as previously found in Bertamini et al. (2016). Through statistical analysis, we have found a significant difference in the size of the region of detected liens in the HC versus the control condition. Showing the stimuli for only a short time is therefore enough to see this effect.

Comparing the Uniform experiment with its Foveal variation, we observe that the additional foveal task reduced the attentional focus, with a decrease of 13% in the illusion and 24% in the control condition (see Table 3). Statistical analysis confirms that the difference between the means of the size of the region populated by stimuli is still significant, in spite of the larger decrease in the control condition. Furthermore, the effect of the addition of the foveal task is significant as well. More interestingly, though, the ANOVA test reveals a significant interaction effect between the introduction of the foveal task and the two conditions of the experiment, meaning that the foveal task has a greater effect when perceiving uniform patterns as such (control) than in the illusion condition. These results suggest that the HC illusion is less subject to the effect of Inattentional Blindness, confirming previous results that have found fewer attention effects in this illusion (Bertamini et al., 2016) and our first hypothesis[2] (H1).

5.2 Blindsight experiment and effect of the foveal task

In the Blindsight experiment, we observed how participants are able to discriminate stimuli (namely, the orientation of the lines) at different sizes of the central region of crosses. The results reported in Figure 12 and Table 4 indicate, as expected, that participants' ability to

[2] We remind the reader we hypothesised that by introducing a foveal task, participants' performance will lower due to divided attention.

Condition	Uniform (baseline) [deg]	Uniform (foveal) [deg]	Reduction [%]
Illusion	13.44±0.24	11.74±0.28	-13
Control	49.23±0.21	37.30±0.41	-24

Table 3: Means of the reported size of the regions with stimuli in the Uniform experiment and its foveal variation.

discriminate was lower in the illusion condition, verified by statistical analysis with a two-way ANOVA test. Similarly, the differences between different sizes of the central region of crosses are found to be significant. Furthermore, the interaction of these effects (condition and size of the central region) is also found to be significant, indicating that participants' dprimes fell significantly faster to 0 in the control condition (at a rate of -0.31±0.03/degree) than the illusion one (-0.22±0.03/degree) for increasingly larger sizes of the central region, as shown in Figure 13.

Condition	d' Blindsight (baseline)	d' Blindsight (foveal)	Reduction [%]
Illusion	1.13±0.17	0.39±0.11	-65
Control	1.73±0.20	1.05±0.18	-40

Table 4: Means of the participants' dprimes in the Blindsight experiment and its foveal variation.

When introducing the additional discriminative task, participants' mean dprimes were understandably lower in both cases, with a relative decrease of 65% in the illusion and 40% in the control. Statistical analysis with a three-way ANOVA verifies that the effects of the foveal task, the condition and the size of the central region of crosses are all significative. We do not find a significant interaction effect of the addition of the foveal task with the condition. We observe indeed that, without the foveal task, there is a difference of 0.6 in the mean dprimes between illusion and control, while with the foveal, the difference is 0.66. This means that the difference in the participants' ability to discriminate stimuli between the illusion and the control conditions remained the same whether they had the additional foveal task or not. Similarly, there is not a significant interaction effect between the addition of the foveal task and the size of the central region of crosses, indicating that the trend of the decrease in participants' performance due to the increasing size of the central region was not affected by the foveal task.

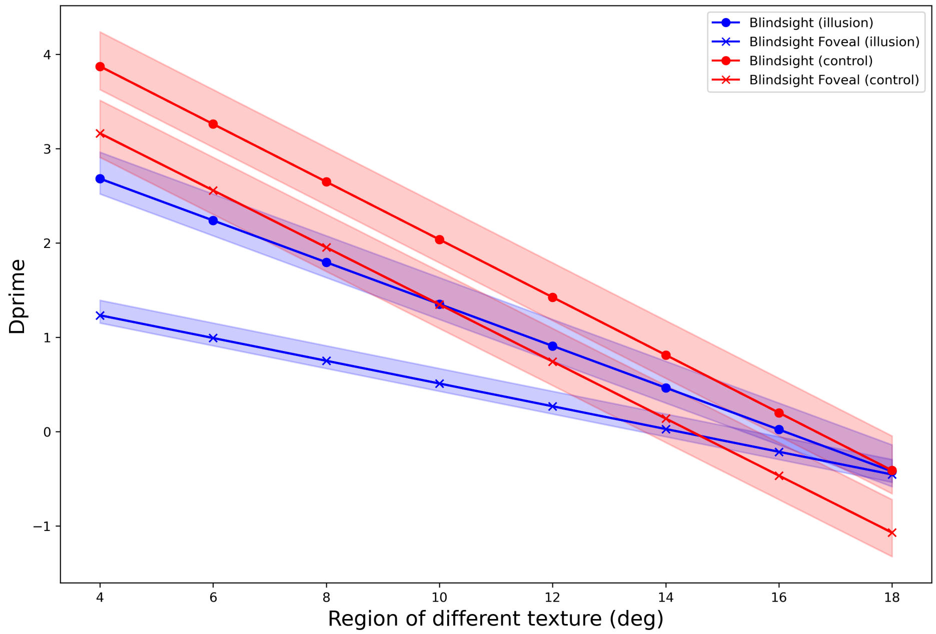


Figure 13: Linear regression of the effect of the condition on participants' accuracies in discriminating the orientation of the stimuli lines, with confidence intervals at 95%. Results are reported both for the Blindsight experiment (circle markers) and its Foveal variation (cross markers), and for both conditions (illusion in blue, control in red).

The interaction between all three of these factors (addition of the foveal task, condition and size of the central region of crosses) is however found to be significant, meaning that introducing the additional foveal task affected differently how fast the participants' accuracies fell to 0 with increasingly larger sizes of the central region of crosses, in the illusion versus the control condition. Figure 13 reports linear regressions on the dprimes as functions of the size of the central region of crosses for the four cases (illusion or control, with or without foveal task). We observe that, indeed, the slopes are smaller in the illusion (-0.22±0.03/degree in the baseline and -0.12±0.02/degree in the foveal variation) compared to the control condition (-0.31±0.03/degree in the baseline and -0.30±0.03 in the foveal variation). The decrease in participants' ability to discriminate stimuli with respect to the size of the central region of crosses, with or without the additional foveal task, is thus significantly lower in the illusion than in the control, further indicating a lesser impact of Inattentional Blindness in the HC illusion.

5.3 Comparison between Uniform and Blindsight experiments

With the first pair of experiments (Uniform experiment), we investigated how far participants are able to detect stimuli, both in the illusion and the control conditions. As previously discussed, participants were only able to detect the stimuli up to a mean of 13.44±0.24 degrees in the illusion condition, while they detected nearly all stimuli (mean of 49.23±0.21, out of a maximum of 52 degrees) in the control condition. On the other hand, in the second pair of experiments (Blindsight experiment), we measured participants' ability to discriminate those stimuli (namely their orientation), finding that participants were able to detect them nearly up to 12 to 14 degrees in the illusion and similarly up to 14 degrees in the control condition (as reported in Figure 12). We can therefore say that, as expected with uniform patterns perceived as such, there is a strong Extrapolation in the control condition, meaning that the participants' vision system assumes that the periphery of their visual field follows the same structure as what they observe directly in their central vision, thus failing to properly discriminate stimuli in the periphery. Inversely, in the illusion, the size of the region in which participants reported to detect stimuli corresponded to the size of the region in which they were able to discriminate them, suggesting there is no Extrapolation in the HC illusion. Our second hypothesis (H2) is thus approved: we have not found evidence of Extrapolation in the HC illusion while confirming it in the control condition.

To conclude, we observe that the additional foveal task did not seem to alter these findings. Indeed, even though the introduction of the foveal task significantly reduced participants' dprimes in both conditions and for both pairs of experiments, it did not change the correspondence in the size of the region in which participants were able to detect stimuli with the size of the region in which they were able to discriminate them, in the illusion condition, contrarily to the case of uniform patterns perceived as they are, for example in the control condition. As reported in Table 3, participants were able to detect stimuli up to 11.74±0.28 degrees in the illusion and 37.30±0.41 degrees in the control, while Figure 12 indicates that their accuracies fall to 0 around 10 to 12 degrees in the first case versus 12 to 14 in the latter. The overlapping between these values in the illusion condition clarifies that in spite of the foveal task, participants' ability to detect stimuli in the HC illusion is not affected much by Inattentional Blindness, contrary to the control condition.

6 Conclusion

In this thesis, we have investigated the effects of two well-known visual mechanisms, Inattentional Blindness and Extrapolation, on the HC illusion, a novel optical illusion proposed by Bertamini et al. (2016). We have carried this research with two pairs of experiments focused on measuring first participants' ability to detect stimuli and then to discriminate them, in the illusion versus the control condition, and with a variation adding an additional foveal task to divide participants' attention.

Results suggest that the HC illusion is less affected by Inattentional Blindness compared to uniform patterns perceived as they are, such as in the control condition, since the size of the region in which participants could detect stimuli decreased by only 13% (compared to 24% in the control). With respect to their abilities to discriminate stimuli, the difference in participants' mean accuracies across all eight possible sizes of the central region of crosses between illusion and control conditions is the same with or without the additional foveal task. There is furthermore a significant interaction effect between addition of the foveal task, condition and size of the central region of crosses. This might therefore indicate that Inattentional Blindness has, here as well, less of an impact in the HC illusion than in uniform patterns perceived as such.

Furthermore, the comparison of the two pairs of experiments reveals a strong likelihood that there is no Extrapolation in the HC illusion since the size of the region in which participants are able to detect stimuli corresponds to the one in which they can discriminate them (around 12 to 14 degrees in the baseline, 10 to 12 in the foveal variation), contrary to pattern uniformly perceived, where nearly the full screen is reported as filled with stimuli but participants could detect them only up to 14 degrees (around 10 to 12 degrees in the foveal variation, for a region of detected stimuli of 70% of the screen). These findings suggest that the HC illusion provides a more authentic vision, compared to filling the gaps in the peripheral vision in uniform patterns perceived as such due to the Extrapolation effect.

This work of research has therefore demonstrated that the HC illusion does not follow well-known visual mechanisms that seemed ubiquitous to our vision, corroborating previous results (Bertamini et al., 2016) and the utility of this optical illusion in studying how our visual system interprets the world.

7 Acknowledgments

Thanks to Prof. Bertamini for the opportunity to conduct this research and his supervision. Thanks to Dott. Oletto for helping me throughout, and being always ready to answer my questions, as well as to the rest of the Visual Perception Laboratory for their welcoming and friendliness.

References

Bergen, J., et al. (1985). Hermann's grid: New and improved. *Investigative Ophthalmology and Visual Science*, *26*, 280.

Bertamini, M., Cretenoud, A. F., & Herzog, M. H. (2019). Exploring the Extent in the Visual Field of the Honeycomb and Extinction Illusions [Publisher: SAGE Publications]. *i-Perception*, *10*(4), 2041669519854784. https://doi.org/10.1177/2041669519854784

Bertamini, M., Herzog, M. H., & Bruno, N. (2016). The Honeycomb illusion: Uniform textures not perceived as such. *i-Perception*, *7*(4), 2041669516660727.

Cohen, J. (2002). The grand Grand Illusion illusion. *Journal of Consciousness Studies*, *9*(5/6), 141–157.

Cook, P. B., & McReynolds, J. S. (1998). Lateral inhibition in the inner retina is important for spatial tuning of ganglion cells. *Nature neuroscience*, *1*(8), 714–719.

Haberman, J., & Whitney, D. (2012). Ensemble Perception: Summarizing the scene and broadening the limits of visual processing.

Hermann, L. (1870). Eine erscheinung simultanen contrastes. *Archiv für die gesamte Physiologie des Menschen und der Tiere*, *3*(1), 13–15.

Mack, A., & Rock, I. (1998). Inattentional blindness: Perception without attention. *Visual attention*, *8*(01).

Ninio, J., & Stevens, K. A. (2000). Variations on the Hermann grid: An extinction illusion. *Perception*, *29*(10), 1209–1217. https://doi.org/10.1068/p2985

Peirce, J. W. (2007). PsychoPy — psychophysics software in python. *Journal of neuroscience methods*, *162*(1-2), 8–13.

Schrauf, M., Lingelbach, B., & Wist, E. R. (1997). The Scintillating Grid Illusion. *Vision Research*, *37*(8), 1033–1038. https://doi.org/10.1016/S0042-6989(96)00255-6

Simons, D. J., Franconeri, S. L., & Reimer, R. L. (2000). Change blindness in the absence of a visual disruption. *Perception*, *29*(10), 1143–1154.

Stewart, E. E. M., Valsecchi, M., & Schütz, A. C. (2020). A review of interactions between peripheral and foveal vision. *Journal of Vision*, *20*(12), 2. https://doi.org/10.1167/jov.20.12.2