Processing, Perception, and Peripheral Vision:

Exploring Variations of the Pinna-Brelstaff Illusion

Though many illusions have been created in recent decades, the introduction of the Pinna-Brelstaff illusion in 2000 marked the first time a visual illusion has shown a rotating motion effect (p. 2091). The illusion consists of two concentric circles, each made of a series of squares (Pinna, 2009). Each square has two connected black sides and two connected white sides, and the squares in the inner circle have their two black sides oriented differently than the squares in the outer circle (see Figure 1, below). The apparent rotating motion effect occurs when the participant's head moves towards and away from the image, and the circles appear to be moving in opposite directions.

In this paper, I will present an overview of existing research on the Pinna-Brelstaff illusion, and show how the studies provide evidence for the three causes of the Pinna-Brelstaff illusion postulated by Pinna and Brelstaff in their initial paper. I will then describe the alterations of the Pinna-Brelstaff illusion that I created to explore the effects of peripheral vision and luminance, and their relation to the postulated causes of the Pinna-Brelstaff illusion. I will describe the results of my experiments, and discuss what conclusions can be drawn.

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The main source of information on the Pinna-Brelstaff illusion is, of course, the 2000 article in which Dr. Baingio Pinna and Dr. Gavin Brelstaff presented the illusion for the first time. In their article, they introduced the illusion (see Figure

1), and describe some of the potential causes of it, including the fact that the “V1-type, motion selective units” (p. 2094) responsible for the illusion sample at a low spatial frequency (and thus perceive the two lines of the same color at a ninety-degree angle as a diagonal line); said units, which are responsible for the illusion, are subject to the aperture effect, and the fact that these units are found in the periphery. These three causes became extremely relevant to my research, and I ended up manipulating various aspects of the illusion based off of these causes.

Figure 1. The original Pinna-Brelstaff illusion. Reprinted from "A new visual illusion of motion," by B. Pinna and G.J. Brelstaff, 2000, *Vision research*, 40, 2091-2096.

Figure 2 (left). The Pinna-Brelstaff illusion with reversed implicit diagonals.

Figure 3 (right). The Pinna-Brelstaff illusion with alternating orientations.

Reprinted from “A new visual illusion of motion,” by B. Pinna and G.J. Brelstaff, 2000, *Vision research*, 40, 2091-2096.

In addition, the authors explored alterations to the Pinna-Brelstaff illusion; most significantly for my research, they described what happens when you rotate the black and white lines of each square by 90 degrees, so as to seemingly ‘reverse’ the location of the implicit diagonals. They found that this does, in fact, reverse the apparent motion of the illusion (Figure 2). They also showed that altering the orientations of the squares so that neighboring pairs have reduced polarity (Figure 3) stops the illusion of apparent motion. In this manner, Pinna and Brelstaff began answering the question of whether altering the composition of the squares would impact the illusion, which is relevant to the research questions I asked myself.

Several studies of the Pinna-Brelstaff illusion already exist. Given my plans to manipulate the composition of the illusion, the studies that explore the boundaries of the illusion were most relevant in my research. The first of these is a study by Gurnsey and Page in 2006, which explores the effects of head self-motion versus computer-induced motion (the so-called ‘zooming’ in and out that causes the apparent motion to appear), as well as the effect of altering either the “global structure” or “micropatterns” of the illusion (p. 1823**)**. Their first set of experiments found that there is no difference in the strength of the illusion when the participant moves their head closer to and farther from the static image, versus when the image is displayed on a computer screen and increased/decreased in size. Additionally, when the participant induces the motion, the strength of the illusion does not vary based on the distance of the head from the illusion. I found this research extremely significant, as it meant that I would not need to control the head position and distance of my participants. Their second set of experiments found that changing the global structure of the illusion (in this case, adding ‘guide’ rings around the circles, as in Figure 4, and adding a square frame around the oval illusion, as in Figure 5) did not impact the strength of the illusion. However, altering the micropatterns of the illusion, and in particular the luminance of the micropatterns, did cause the illusion’s strength to drastically decrease. The two manipulations performed included ‘half-wave rectifying’ the micropatterns, which means that **“**all luminance values below the mean luminance are set to the background luminance," (p. 1831) (Figure 6) and 'hard-edged apertures,' in which the blurred lines of the micropatterns are made sharp (Figure 7)

(Gurnsey and Page, 2006). Both of these manipulations drastically reduced the strength of the illusion, which Gurnsey and Page suggest is related to the fact that "the bandwidth effect shows that the visual system fails to solve the aperture problem only when the micropatterns making up the stimulus are narrowband" (p. 1835), or over a small range of spatial frequencies. This study, then, provides evidence for one of the three causes Pinna and Brelstaff proposed for the illusion: that the aperture effect is necessary for the illusion to function properly.

Figure 4. The Pinna-Brelstaff illusion with guide rings added. *Figure 5*. The Pinna-Brelstaff illusion with a square border. *Figure 6*. The Pinna-Brelstaff illusion with half-wave rectified Gabor patches. *Figure 7*. The Pinna-Brelstaff illusion with hard-edged apertures. Reprinted from "Effects of local and global factors in the Pinna illusion," by R. Gurnsey and G. Pagé, 2006, *Vision Research*, 46, 1823-1837.

In these figures, one might notice that the micropatterns are not the same squares as in Pinna and Brelstaff's original presentation of the illusion (compare, for instance, figures 4 and 1) (Brelstaff & Pinna, 2000). This is due to a finding in Gurnsey et al.'s study, aptly titled "Optimizing the Pinna-Brelstaff Illusion," in which the researchers explore how to increase the strength of the aforementioned illusion (Gurnsey et al., 2000). The primary finding from this article is that blurring the squares to transform them

2000). The primary finding from this article is that blurring the squares to transform them into Gabor patches increases the response of the neurons that are sensitive to the specific direction of motion, thus increasing the strength of the illusion. This provides evidence for the second of Pinna and Brelstaff's proposed causes of the illusion, which is that low-frequency sampling is responsible for the illusion, confirming Bayerl and Neumann's conclusion from previous research into the Pinna-Brelstaff illusion that replacing squares with Gabor patches illuminates the role of low spatial frequency light gradients (2002). As the authors state, "[t]hese results support the suggestion of Pinna and Brelstaff (2000) that the low- frequency orientation structure in their patterns generates their illusion" (p. 1279). However, due to the fact that I planned on manipulating the size and luminance of the illusion, I chose to retain the square pattern from Pinna and Brelstaff's initial presentation of the illusion, since it would be far more complicated to alter a Gabor patch than plain lines.

Additional relevant research into how the illusion is processed suggests that higher-level processing is necessary for the illusion. This conclusion can be drawn based off of studies by Budnik et al. in 2006 and Nakayama and Silverman (Budnik et al. 2006). Nakayama and Silverman's 2008 fMRI studies suggest that area MT and dorsal

2006). Nakayama and Silverman's 2008 fMRI studies suggest that area MT and dorsal MST are active when viewing the illusion, whose function is to "collate all the signals provided by the local motion micropatterns" (748). Budnik's research also showed activation of hMT+, known to be a motion-specific region. This research suggests that viewing the illusion activates the same brain areas as viewing actual motion does, meaning that research questions about the cause of the illusion could have practical implications for research on viewing actual, and not just perceived, motion.

In my work, I categorized the variety of information about the Pinna-Brelstaff illusion based on the three proposed causes of the illusion: the peripheral nature of the motion detector cells, the low-spatial frequency sampling of the illusion, and the aperture effect that the motion detector cells are subject to. As mentioned above, there have been studies that provide evidence for the low-spatial frequency, such as Gurnsey et al.'s research on optimizing the illusion (2002). Gurnsey and Page's research into altering the micropatterns of the illusion lends credence to the notion that the aperture effect is a part of processing this illusion (2006). In addition, many known illusions rely on the aperture effect, and Burr and Thompson's 2011 review of visual motion research from 1985-2010 notes that "the explanation [for the Pinna-Brelstaff illusion] seems to lie with the aperture effect" (1447). I found these studies particularly compelling, and support at least these two of the three proposed causes of the illusion.

However, none of this research addressed the fact that Pinna and Brelstaff (2000) postulated that peripheral vision is necessary for the illusion to function. Their suggestion was rooted in the fact that the illusion is based off of the implicit diagonals of the squares, which "have a strong orientation once they are blurred, as they are when they fall on peripheral vision" (Burr & Thompson, 2011; Pinna & Spillman, 2005). I decided to ask myself the question: what would happen if you changed the 'global structure' of the illusion, to use Gurnsey and Page's words, to test the theory that peripheral vision is necessary for the illusion to function? And more specifically: what would happen if you kept one circle in the periphery, but brought the other (inner) circle into the fovea? What would happen if you increased the overall diameter of the illusion, and brought both circles further out in the periphery?

In addition, I wanted to explore the luminance and contrast of the circles. Gurnsey and Page's 2006 experiment showed that eliminating all luminance in a

Gabor patch that was less than the mean luminance would decrease the effect of the illusion. I wanted to see, however, how the relationship between the shades of black, white, and the gray of the background impacted the strength of the illusion. In particular, I asked the question: does decreasing the luminance of the white lines and the black lines have the same effect on the overall illusory effect?

In order to answer my questions about the impact of peripheral vision on the illusion, I created variations of the illusion. I had some boundaries that I followed in manipulating the original illusion: as I increased or decreased the diameter of the illusion, I would keep the distance between each square the same (96 pixels). I also kept the colors of the image, the size of the squares, and the color and size of the 'focal' dot in the center of the image the same, in order to eliminate confounding variables that could have arisen.

In one of my alterations, I kept the outer circle the same, but brought the inner circle closer to the focal point (see Figure 8a, below). I altered the illusion so that the inner circle was halfway between the focal point and the outside circle that the inner circle was halfway between the focal point and the outside circle. This was the alteration intended to test what impact keeping one of the circles in the periphery, but moving one to the fovea, would have. In the second alteration, I kept the distance between the inner and outer circle the same, but increased the overall diameter of the illusion (see Figure 8b), in order to see if making the circles 'more peripheral' could strengthen the illusion.

Figure 8a (left). The Pinna-Brelstaff illusion with the diameter of the inner circle reduced. *Figure 8b (right)*. The Pinna-Brelstaff illusion with the diameter of both circles increased.

For my explorations of the luminance and contrast, I kept the size, shape, and orientation of the image the same, only changing the colors of the squares. Since the main question I was trying to answer how reducing the luminance of either color in the illusion, rather than the overall luminance, I chose to alter the illusion in three ways. In the first alteration, I kept the gray background, white parts of the square, and black focal point the same color, and changed the white parts of the squares so that the luminance was halfway between the original white color and the gray background of the square (see Figure 9b). For my second alteration, I did the same thing, except I kept the white color of the square

constant, and lightened the black parts of the squares to halfway between the original shade of black and the gray of the background (see Figure 9c). I also presented a third alteration, in which both the white and black parts of the squares were dulled to half-saturation, similar to the half-wave rectification of Gurnsey and Page (see Figure 9d).

Figures 9a (top left). The original Pinna-Brelstaff illusion. *Figure 9b (top right)*. The Pinna-Brelstaff illusion with dulled white sides. *Figure 9c (bottom left)*. The Pinna-Brelstaff illusion with dulled black sides. *Figure 9d (bottom right)*. The Pinna-Brelstaff illusion with dulled black and white sides.

Pinna-Brelstaff illusion with dulled black and white sides.

My explorations of the impact of peripheral vision on the illusion yielded clear results. For the first alteration (Figure 8a), in which I brought the inner circle

closer towards the focal point, I found that the rotating motion effect seemed diminished, in accordance with my expectations. What is interesting is that the apparent motion of both the inner and outer circle seemed diminished. This seems to suggest that the apparent motion of each circle depends on the position of the other; if this were not true, the outer circle would still appear to be rotating, while the inner circle would not. This supports Pinna and Brelstaff's suggestion that the illusion does not work in foveal vision, but rather relies on peripheral vision; however, it also supports the suggestion that peripheral motion detectors are not solely responsible for the illusion, and that there is some top-down processing over the overall structure that influences perception of the illusion.

The second alteration involving peripheral vision, in which both circles were extended further into peripheral space (see Figure 8b), participants reported an increased sensation of rotating motion, as I expected. This seems to further affirm Pinna and Brelstaff's suggestion that peripheral vision is necessary for the illusion to function, and one could extrapolate from this data that the further in the periphery the illusion is, the more effective it is. However, I would raise the question of whether or not the number of squares present in each circle impacts the efficacy of the illusion. The method of increasing the diameter of the circle that I used involved increasing the number of squares in each circle. Additional studies

are necessary, focusing on both foveal and peripheral versions of the illusion, that focus on changing the number of squares in each circle, and seeing whether the

number of squares influences the apparent motion effect. If, as I anticipate, the increased number of squares causes increase apparent motion effect, then I would be wary of assuming that the increased diameter of the illusion in Figure 8b inherently increases the strength of the illusion.

My second set of experiments explored the effect of changing the luminance of the squares in the illusion. The first alteration, where I decreased the luminance of the white sides of the squares (Figure 9b**)**, resulted in the participants reporting that the illusory motion effect was diminished, or that the circles appeared to be rotating more slowly. In the second alteration, where the white sides of the squares were at full luminance but the black sides were dulled **(**Figure 9c), none of my participants noted a decrease of the effect. In the third alteration, where both the white and black parts of the squares were dulled (Figure 9d), participants either noted no difference between that alteration and the 'basic' image (Figure 9a) or noted that the effect was diminished in the alteration.

The pattern of responses to these alterations suggests to me that the it is the luminance of the white sides of the squares that is most significant in determining the strength of the illusion**-** when the white parts of the squares are dimmed, the illusion seems to decrease. One possible explanation for this involves the fact that peripheral cells, as shown above, are actively involved in perceiving this illusion.

The periphery of the retina is dominated by rod cells, which are more sensitive to light than the cones of the fovea (Stiles, 1939, p.65) It is possible that, because

these rods are so much more sensitive to light than cones, they show a greater response to a reduction of contrast in the spatial frequencies of light colors than in the spatial frequencies of dark colors. If this is the case, then it would make sense that decreasing the luminance of the white sides of the squares would cause a noted decreased in the strength of the illusion.

There are two considerations to keep in mind while reviewing the results of these experiments, and to consider while going forward. The first is that my sample size was small; only four participants were recruited, and while the results I recorded supported my conclusions, they may be statistically insignificant. The second is that I had no method of ensuring that the rate of head motion of the participants towards and away from the screen was constant; there is bound to be some individual variation. Although I did not tell participants my hypotheses ahead of time, my phrasing in introducing the illusion may have biased their perception of the illusion, and I would not firmly conclude any of my findings until replicating them under more standardized conditions. For future research, I would find it interesting to explore whether the findings of these experiments can be applied to other illusions that rely on peripheral motion or contrasting luminance. There is much work yet to be done on the Pinna-Brelstaff illusion, and I look forward to the insights and revelations that this research will certainly yield.

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