ILLUSIONS OUTSIDE THEIR COMFORT ZONE: THE MÜLLER-LYER-ILLUSION IN THE PARAFOVEA (DRAFT VERSION 1.8)

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Abstract

The Müller-Lyer illusion is often only presented foveallly, in the center of the visual field. Here, we investigate how the strength of the Mller-Lyer-Illusion increases if shown parafoveally. We suggest an explanation of the effect in terms of increased receptive field size and corresponding coarseness of the content of perception. We also analyse outliers and argue that they use different strategies for processing the stimulus parafoveally in order to decrease or even invert the effect.

1. Introduction

We do not perceive the world in the same way as our experience of it makes us believe, specifically in the parafovea: It looks as if we perceive colours in the periphery of our visual field, but we don't (Blackmore et al., 1995, Hansen et al., 2009, Strasburger et al., 2011); it looks as if we perceive concrete shapes outside our center of vision, but a bunch of differently distorted stimuli that have similar statistical features (so called *metamers*) look the same (Freeman and Simoncelli, 2010, 2011, Anderson et al., 2012, Block, 2013, Cohen et al., 2016); it looks as if a stimulus is uniform even though its center differs considerably from its periphery (Otten et al., 2017); it may look as if the right and left of a stimulus are aligned although they aren't (Chen et al., 2018). Stimulation is therefore differently processed in the fovea compared to the parafovea: Most of what we experience as happening in the outskirts of our visual field is constructed and influenced by internal factors, based on our brain's best guess. However, we also know that attention alters the appearance of stimuli in the periphery (Carrasco et al., 2004, Carrasco, 2009, Gobell and Carrasco, 2005), arguably in order to allow for greater precision (Block 2012, 2014, 2015a, 2015b; cf. Fink 2015).

This raises the question: How are *illusory* stimuli perceived in the periphery of the visual field? For this question, *color* illusions are hardly appropriate due to the comparative lack of cone cells in the parafovea compared to the fovea (Abramov et al., 1991, Abramov and Gordon, 1977, Gordon and Abramov, 1977, Nagy and Wolf, 1993). There is some evidence of slight differences concerning contrast perception (Carrasco et al., 2001, Cameron et al., 2002) between vision's periphery and center which may even vary between subjects (Greenwood et al., 2017). Still, *geometrical* illusions appear to be better suited to investigate illusions in the periphery than coloured ones as basic processes are sufficiently similar. Here, we therefore explore the peripheral effects on one of the oldest geometrical illusions, the Müller-Lyer (Müller-Lyer, 1889, Fisher, 1970, Restle and Decker, 1977).

Does eccentric presentation have any effect at all on the illusion? If so, does the illusion de- or increase when presented outside the center of vision and while suppressing saccades to bring it into the center of vision? Both a weakening and a strengthening of the illusion will be measurable psychophysically when comparing a peripheral presentation to normal viewing conditions. But it is quite unclear what to expect: On the one hand, the coarser grained, metamere-prone and enlarged receptive fields of peripheral neurons in the visual cortex could lead to a measurable overestimation of the stimuli; on the other hand, the attentional enhancement effects outside the fovea with the suppressed contributions of saccades to the illusion might either to counter these effects and even weaken the illusion. A priori, both are plausible. So far, no study has empirically tested the Müller-Lyer Illusion in the periphery, but an exploratory pilot-study by one of the authors at the University of Osnabrück's *Institute for Cognitive Science* lead to a near elimination of the illusion in the periphery, which invited a more rigorous exploration. In order to resolve the impasse between different plausible empirically grounded hypotheses, we performed the following experiment.

2. Methods

2.1. **Subjects.** 21 subjects aged 20-36 ($\sigma = 4.56$, $\overline{x} = 26.4$) voluntarily participated the experiment. The data of one participant could not be considered due to a technical issue. The remaining sample consists of 7 female and 13 male subjects. The participants had either no visual impairment or vision corrected to normal. 13 participants had previous knowledge of the Müller-Lyer-Illusion and two already took part in experiments on the Müller-Lyer-Illusion. 8 participants had participated in other psychophysical studies. Subject 21 is one of the authors and co-designed the experiment, all other subjects were naïve.

2.2. **Materials.** The experiment was executed in the *Laboratory for Philosophy–Neurosciences–Cogntion* (PNK-Lab) at the Otto-von-Guericke-University Magdeburg. The room was slightly darkened, illuminated only by indirect, stable, artificial light, one above and behind the participant and one directly behind the monitor. The computer was an HP Pavilion 15-bc009ng (Intel Core i5-6300HQ, 8GB RAM, NVIDIA GeForce GTX 960M, Win 10) and was attached to a screen (NEC EA224WMi) with 22 inch and 1920x1080 pixels. The participants communicated their decisions by the arrow keys of a standard keyboard. The code for the stimulus presentation was written in python using the Psychopy toolbox and developed in Spyder. The subsequent evaluation was done in Matlab R2016a.

2.3. **Stimulus.** We presented variations on the Brentano-version of the Müller-Lyer-illusion. Girgus et al. (1973) compared different variants (original, variants of Fisher and variants of Brentano) and found that the Brentano-variant is one of the most effective.[1] The horizontal line was 1mm thick and had a total length 20cm, which gives a visual angle of 20°. The length of the horizontal axis was fixed while three parameters could vary: (i) the angle of the arrow heads, (ii) where the center arrow head intersected the horizontal, and (iii) the direction of the arrow heads, e.g. left pointing inwards vs. outward. Tab. 2.3 shows the distance of stimuli from the edges of the screen, which varied with the different angles.

The angles between the horizontal and the wings of the arrow heads were varied, but were homogeneous for each arrow head in each stimulus. The illusion increases with the apex of the angles (Dewar, 1967, Fisher, 1970, Girgus et al., 1973, Heymans, 1896), so we opted for well established angles of 15°, 30°, and 45° divergence from the perpendicular axis (see fig. 1). This

[1] There may be a possible advantage of the Fisher-Stimulus as it offers less *Tiefenreize* (Fisher, 1970), but this conjecture is irrelevant here.

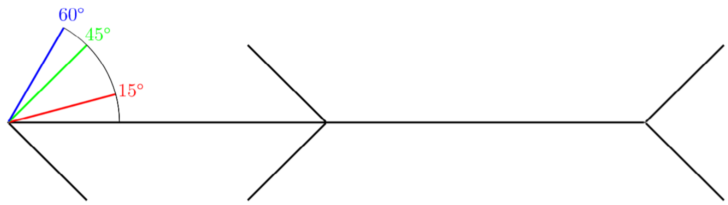

FIGURE 1. Three different angles used.

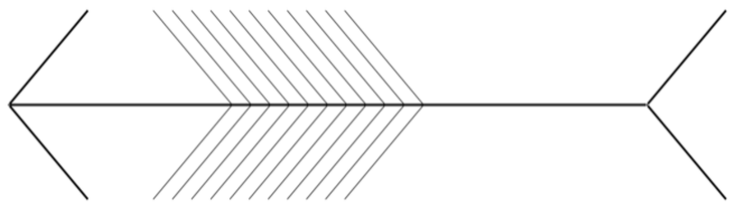

FIGURE 2. Positions of the twelve different points of intersection

allows for investigating if this variable of the illusion remains when presented in the periphery and ensures comparability with established literature.

The horizontal of the stimulus was intersected by a middle arrow head. The intersection could happen between from 35% to 65% of the horizontal in increments of 3% (i.e roughly at 7, 7.6, 8.2, 8.8, 9.4, 10, 10.6, 11.2, 11.8, 12.4, 13cm,[2] see fig. 2). Previous studies found that for the original Müller-Lyer-version (which presents one figure above another), arrow heads with the length of 30-40% of the horizontal maximise the magnitude of the illusion (Lewis, 1909, Restle and Decker, 1977). For a Brentano figure, where the horizontal is twice as long, the illusion is maximal with a arrow head length of 15-20% of the total horizontal, wherefore we opted

[2]Intersections were calculated in percent of the length of the horizontal and therefore do not match directly smooth numbers on the metric scale. We include an approximation for easier understanding.

Angle	Distance from horizontal edges	Distance from upper edge	Distance from lower edge	Overall length	Overall height
F-15°	12.0	12.2	12.2	23.4	2.0
F-45°	12.5	10.9	10.9	22.4	4.6
F-60°	13.0	10.3	10.3	21.8	5.8
P-15°	12.0	5.4	19.0	23.4	2.0
P-45°	12.5	4.1	17.7	22.4	4.6
P-60°	13.0	3.5	17.1	21.8	5.8

TABLE 1. Placement of the stimulus on the display (length in cm).

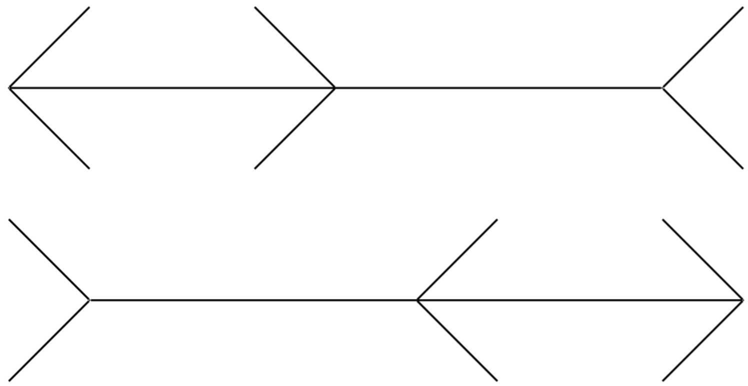

FIGURE 3. Orientation: Upper is left handed, lower is right handed.

for a constant length 17.5% of the horizontal (3.5cm). Lastly, each angle-intersection-configuration could be left or right handed, where the direction denotes the location of the outside pointing arrow head (see fig. 3). The section flanked by arrow heads pointing outward is the outward section, the section flanked by arrow heads pointing inward is the inward section. Therefore, in a left handed figure, the outward section is to the left, in a right handed figure, the outward section is on the right.

With three different angles, eleven positions for the intersection as well as left vs. right handed stimuli, we presented (3 x 11 x 2 =) 66 different variants of the Brentano-Müller-Lyer stimulus. Each variation was shown twelve times leading to (66 x 12 =) 792 trials per condition.

2.4. **Conditions.** The experiment compared two conditions: In condition F (*free view*), the stimuli were presented in the middle of the screen and subjects could make non-inhibited, natural saccades; in condition P (*peripheral view*), a fixation point was presented in the middle of the screen, subjects had to suppress saccades by fixating on it while the stimuli were presented in the upper visual field with 6.6° visual angle as the distance between the fixation point to the midpoint of the stimulus' horizontal. The usual distance from the subject to the stimulus is 40 to 60cm (Bolles, 1969, Burnham, 1968, Girgus et al., 1973, Giovannella and Galli, 2010, Porac, 1994, Restle and Decker, 1977). For smooth conversion of distance to visual angle, a distance of 57cm was chosen, where 1cm on the screen corresponds to 1° visual angle.

For P, the fixation aid was a red circle with a diameter of 7mm with a centered white dot of 1.5mm diameter, presented a distance of 23.5cm to horizontal and 13.0cm to vertical edges of the screen. We decided against a standard fixation cross in order to minimise imaginary extension of its lines as an aid for judging the stimuli. We chose the upper visual periphery because Hafed and Chen (2016) argued convincingly that the upper visual field has advantages for a number of different perceptual tasks in the periphery: The receptive fields in the upper visual field are smaller, faster and better suited to capture spatial structures. Therefore, if there is a difference in central vs. peripheral illusions, it should be most pronounced in the upper visual periphery.

In each conditions and for each stimuli, subject had to make a two-alternative forced choice: Indicate by pressing the arrow keys which side of the horizontal appears longer than the other. Subjects had no time limit for their decision.

2.5. **Procedure.** Subjects performed in two session, one for each condition, at least two days apart, half of them beginning with F, the other with P. They completed a questionnaire and were instructed on the task. We emphasised that it is a pure perception task and the knowledge of the illusion, if any, should not be taken into account. Furthermore, subjects were instructed to prefer on accuracy over speed. After a training block with 24 random trials, subjects were left alone for the experimental conditions. The different stimuli were presented in a pseudo-randomized constancy method. The actual experiment with 792 trials was divided into three blocks of 200 and one block of 192 trials, separated by a break of 60 seconds. Each trail was separated by a random interstimulus interval of 0.5 to 2.0 seconds, which prohibited a rhythmic or mechanic response. Each session lasted between 30-40 minutes. At the end of each condition, subjects were asked to rate their confidence in their task performance on a scale of 1 to 10 (see App. 5.1).

2.6. **Evaluation.** The collected data was analysed by a generalised linear mixed model, which applies in cases where correlations within the data or the target variable are not normally distributed. This applies to our experiment where only two characteristics were targeted: the stimuli varied (i) in their direction (left/right), (ii) in the angel of the arrow heads ($15°/45°/60°$), and (iii) where they were presented (in the center or periphery of the visual field); of these, only the last two where of interest here.

The data is visualised using logistic regression. The point of subjective equality (PSE) results from the logistic regression and represents the estimated point at which the probability for both answers is 50%. In such a case, a subject was unable to reliable tell whether the right or left side appeared longer and therefore answered randomly.

3. Results

Our data suggests that the magnitude of the illusion increases in condition P (stimulus presented in the periphery) compared to condition F (stimulus presented for free viewing). In fig. 4, the y-axis represents the probability that a subject will judge as longer that section of the stimulus where the arrow heads are pointing outwards over that section with arrow

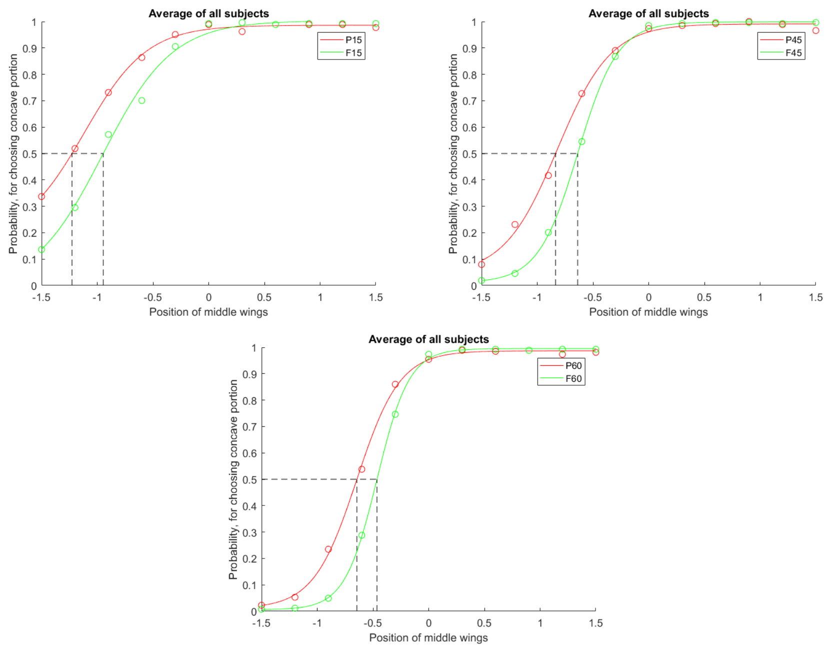

FIGURE 4. Comparison between F and P for different angles ($15°$, $45°$, $60°$), averaged over all subjects, with point of subjective equality marked by the horizontal line.

heads pointing inwards while the x-axis represents the deviation of middle arrowhead from the physical middle of horizontal line of the stimulus. Where subjects judge at chance level (0.5 on the y-axis), we find the point of subjective equality (PSE) where a stimulus looks as if the center arrow head were in the middle of the horizontal line. The closer the PSE is to the real middle of the physical line, the weaker the illusion; the further apart, the stronger. The deviation of the PSE from one condition to the other is marked for easy comparison. Data from mirror symmetric stimuli (e.g. left arrow head pointing outward and right arrow head pointing outward with the same deviation of the center arrow head from the middle) were combined and averaged by logistic regression over all subjects and all trials.

For each of the three different angles of the arrow heads, we found an increase of the magnitude of the illusion in the periphery. Results for individual subjects show some variability but points to the same direction, suggesting that the effect was not an artefact of averaging. Fig. 5 presents the data of three chosen subjects: a standard subject (09), subject 21 who showed a decrease of the illusion in one angle, and subject 12 who showed no effect for one angle.

The upper three graphs are the evaluation of a subjects data whose results are similar to the average of all subjects. It can be clearly seen that for all three angle variations, the graph for condition P is pushed to the left. The curves for the condition F at the 45° and 60° angles do not have a probability of 1 in the graph. This circumstance is due to individual trials in the range x $\geq$ 0.5 at which the subject accidentally responded wrong. Even though the probability in the actual data is partly 1, logistic regression approximates this by a graph that never reaches a probability of 1. The three middle curves of the subject 021 are quite different from the average. For the 60° and 45° angles, there is little difference between the two conditions. In the case of the 15° variation, even an opposite result seems to emerge. The Frei15 curve shows a larger illusion for some x values $\geq$ 0.42 than in the Peri15 curve. This means that for subject 021 an increased magnitude of the illusion can be observed during free observation of the stimulus, while the presentation in the periphery results in a less strong illusion. It should also be noted that the effect between the different angles is not particularly pronounced. Although it is possible to observe a very light shift to the left when comparing the angles, it is a small distance. Subject 021 does not only fall out of the grid in terms of the effect between the conditions, but also in terms of the effect between the different angles. From the questionnaire it can be seen that the subject not only had knowledge of the object of investigation, but also participated in a variety of other psychophysical studies. In addition, the subject stated a confidence of 6 on a scale of 1 to 10 under both conditions. A large part of the subjects, on the other hand, were less confident under condition P.

Finally, another test person has been noticed whose curves are shown in the lower part of fig. 5. The two waveforms titled Subject 012 Peri60 vs. Frei60 are almost identical. For the subject, the two conditions in the 60°-variation virtually did not differ. The presentation of the stimulus in the periphery did not affect the magnitude of the illusion. Interestingly, the curves of the Frei60 and Frei45 graph are also nearly identical. In the condition F, the magnitude of the illusion between the 60° and the 45° variations does not differ. Only at the 15° variation a slight shift to the left can be seen. But it remains to be noted that the effect between different angles while free observation of the Müller-Lyer illusion is hardly recognizable for this person. Remarkably, the effect between the angles seems to occur under condition P. There are clear distances between the Peri60, Peri45 and Peri15 graphs. It is the case here that the typical increase in the illusion for acute angles does not occur in condition F, but this effect occurs when the stimulus is observed in the periphery. This has not only occurred with this subject, but to the same extent, or at least partly with subjects 017, 016 and 011.Of the four people affected, only subject 012 has first completed condition F and then condition P. Since the effect just described occurs most in the case of subject 021, an explanation based on the order of the conditions is unlikely.

The sharp slope of the obtuse angle curves also shows the consistency of the decisions of subject 012. For the same stimulus variations, the subject made the same decisions. The flatter and straighter the curve turns out, the

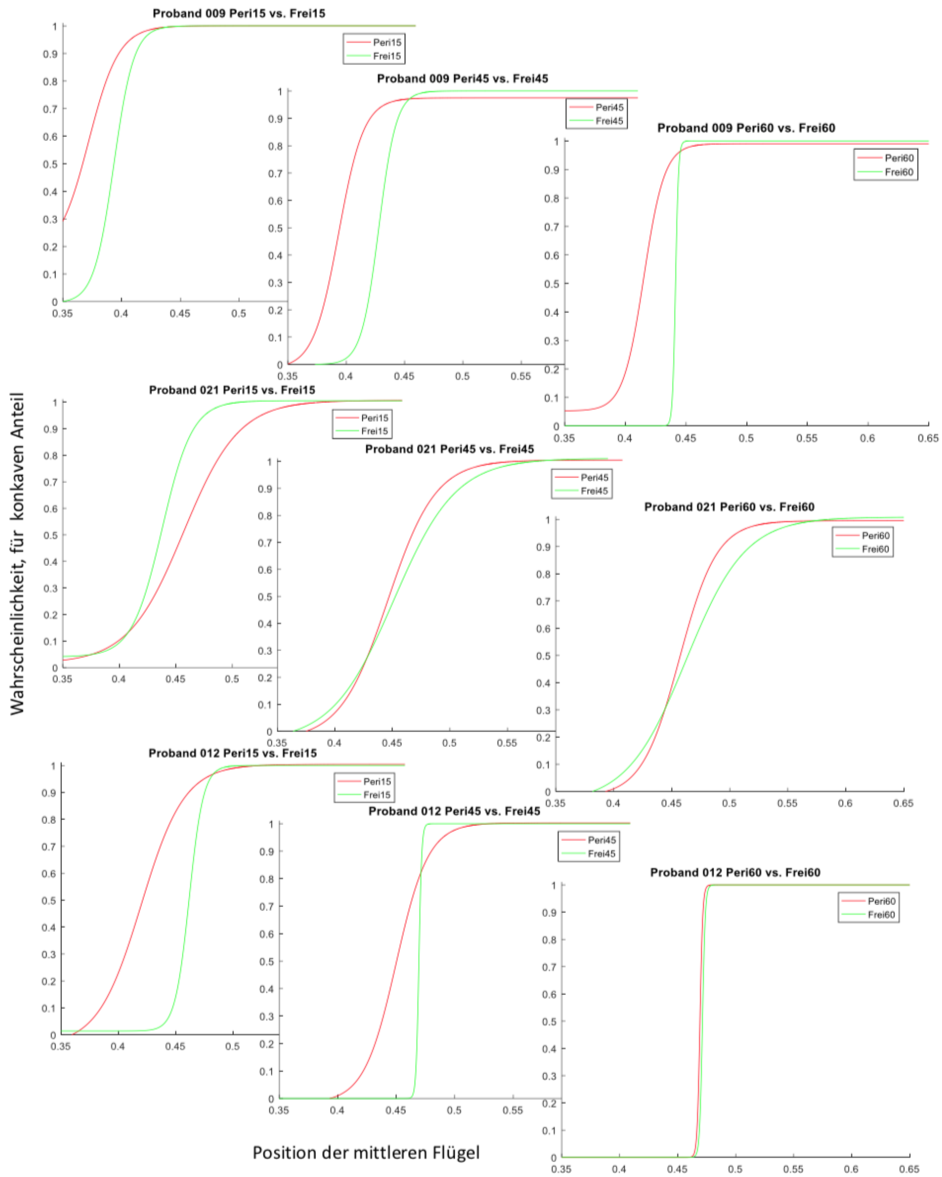

FIGURE 5. Psychophysical curves of three subjects, representing three different types of response-difference for the foveal/parafoveal presentation: Subject 009 showed an increase in the magnitude of the illusion, subject 021 a slight decrease in illusion size, subject 012 showed nearly identical response.

more uncertain the subject seems to be. Increasingly flatter curves under condition P can also be seen at subjects 017, 016 and 011, among others.

Angle	PSE-F	Magnitude of Illusion in F	PSE-P	Magnitude of Illusion in P	Comp. Increase from F to P
15°	0,405	9,6%	0,377	12,3%	128,1%
45°	0,436	6,3%	0,416	8,4%	133,3%
60°	0,453	4,5%	0,435	6,3%	140,0%

TABLE 2. The point of subjective equality (PSE) is an indicator for the magnitude of the illusion. The proportional increase of the magnitude of the illusion in one condition is calculated by subtracting the PSE of each condition from the actual middle of the intersection of the physical stimulus, i.e. 0.5−PSE. The last column gives the comparative increase of the magnitude of the illusion from one condition to the other (PSE-Peri/PSE-Free).

3.1. **Point of Subjective Equality.** Tab. 3.1 shows average PSE values calculated on the basis of all subjects. There is a clear trend: the magnitude of the illusion in condition P increases by about one-third of the illusion present in condition F. The 60° angle, in relative terms, causes the greatest change in the illusion. The columns PSE(Frei) and PSE(Peri) represent the PSE values for the two conditions as a function of the angle. Since 0.5 represents the point of physical equality, the values of 0.5 were subtracted in each successive column to determine the degree of illusion. The last column shows how much the illusion of condition F changes to condition P. The PSE values are shown in the table as a percentage of the horizontal. For example, the PSE for the condition F is about 0.41 using the 15° variation. This corresponds to about 41% of the horizontal. In order to be able to specify the actual value in centimeters, the respective value must be multiplied by the length of the horizontal. For the example mentioned this gives 0.41 x 20cm = 8.2cm. So while the physical center is 10cm (0.5 x 20cm = 10cm), the average subjective center is 8.2cm.

It can be noted that the 15° variation of condition P produces an illusion of 12.3%, whereas in condition F only 9.6% was measured. Condition P thus produces 128.1% of the illusion in condition F, as can be seen from the division results in the last column. The magnitude of the illusion has therefore increased by almost a third. For the 45° variation, the table shows an increase of exactly one third (133.3%), and for the 60° angle even two fifths (140%). This is difficult to see in figure 14, as the data are dependent on the illusion in Condition F. The increase of the illusion for the 60° angle as such is less than at the other angles, but in relation to the illusion measured in condition F, the magnitude of the illusion in condition P increases the most.

Since the logistic regression is an approximation method and the PSE is calculated through this method, a final check of the values is to be carried out. The results shown in the table were compiled from the already merged data. That means, that the data was first averaged and then the PSE was calculated. As a control, the PSE calues of all subjects were first calculated and then averaged **(see Appendix 3 for PSE values)**. In this case, a deviation of a maximum of 3.2mm was found, which corresponds to a small difference of a maximum of 0.016%.

4. Discussion

Our data strongly indicates that the magnitude of the Müller-Lyer Illusion increases in the periphery. Furthermore, aspects that increase the magnitude of the illusion of in the center of the visual field (like the angle of the arrow heads) still influence the magnitude of the illusion in the periphery. While there are some slight differences between individuals concerning specific increase of the illusion (with subject 12 and 21 being the extremes for some specific variants), this effect appears highly stable across individuals. We also saw a slight effect when it came to orientation, which must be investigated in future studies. If it persists, it might relate to different perceptual accuracy in the quadrants of peripheral vision (Cameron et al., 2002, Hafed and Chen, 2016).

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4.1. **Noise, Increased Field Size, and Hierarchical Predictive Coding.** One way to explain the increase of illusory size in the periphery relies on the increase of receptive fields towards the outside of the visual field: In the periphery, cells receptive to visual stimuli average over a larger portion of physical space, e.g. more and more arc minutes.

We suggest the following predicitive coding model: cells in the lower levels of the visual hierarchy represent stimulus presence in larger or smaller portion of physical space, dependent on whether they code closer to the fovea or the periphery. Cells in higher levels of the visual cortex must predict the length of lines. For an area α, which is not part the horizontal line but beyond its end (represented in blue), higher level cells must decide whether α should count as part of the line or not. For this task, information from receptive fields adjacent to α is taken into account. In the case of an arrowhead, adjacent cells provide no conflicting information, for only one cell adjacent codes for stimulus presence. Therefore, in the case of arrow head, higher level cells count α as being empty. For a fin, adjacent cells do code for stimulus presence. Depending on the noise associated with the receptive field for α, higher order cells may count the inactivation of that receptive field as noise and count α as being part of the horizontal line. With an increase in receptive field size (compare top vs. bottom in fig. 6), what is counted as part of the line increases as well. Therefore, we should therefore see an increase in illusory size with an increase in receptive field size in such a predictive coding model.

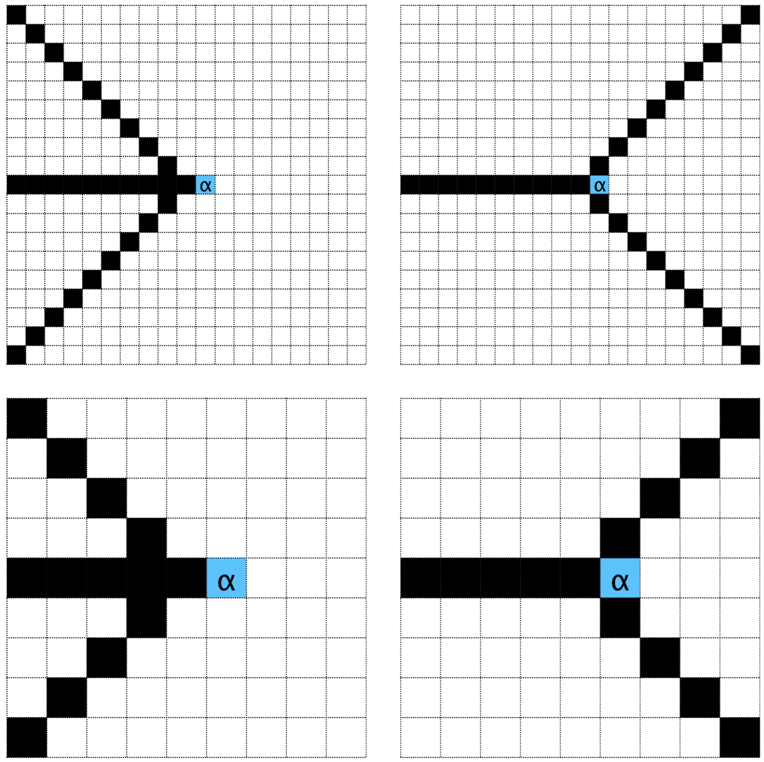

FIGURE 6. With an increase in receptive field size, a larger portion of physical space α (here in blue) must be either counted or discounted as part of the horizontal line in the Müller-Lyer-Illusion. In a predictive coding framework, each activation of receptive field should be associated with some noise, whereby adjacent information is taken into account to decide whether to count or discount α as part of the horizontal line. In the case of an arrow head (left), adjacent receptive fields give no conflicting information for α lacking a stimulus; in the case of a fin (right), three of four adjacent receptive fields are active and therefore give conflicting information. Depending on the noise associated with the receptive field of α, this may lead to α being counted as part of the horizontal line. With an increase of receptive field size (top vs. bottom) comes an increase of the space associated with α, which explains an increase of the illusion in the periphery.

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5. Appendices

5.1. Appendix 1: Questionnaire.

5.1.1. *Pre-Experiment Questionnaire.*

- Datum: Probanden-Nummer:
  [*Date: Participant Number:*]
- Welches Geschlecht haben Sie?
  [*What is your biological sex?*]
- Wann sind Sie geboren?
  [*When were you born?*]
- Ist Ihr Sehvermögen auf irgendeine Art und Weise beeinträchtigt? Wenn ja, auf welche und ist die Sehfähigkeit auf normal korrigiert?
  [*Is you vision impaired in any way? If yes, in which way and is it corrected to normal?*]
- Hatten Sie vor Durchführung des Experimentes bereits Kenntnis über die Müller-Lyer-Illusion oder ähnliche Illusionen?
  [*Have you known the Müller-Lyer or similar illusions before coming to this experiment?*]
- Haben Sie schon öfter an psychophysikalischen Experimenten teilgenommen? Wenn ja, an welchen und wie oft?
  [*Have you previously participated in psychophysical experiments? If yes, which ones and how often?*]

5.1.2. *Post-Experiment Questionnaire.*

- Datum: Probanden-Nummer:
  [*Date: Participant Number:*]
- Selbstsicherheit des Probanden
  ⟨1 (sehr unsicher) — 10 (sehr sicher)⟩
  [*Self-Estimation of Task Performance*
  ⟨1 (very inconfident of one's performance) — 10 (very confident of one's performance)⟩]
- Bemerkungen und Kommentare des Probanden:
  [*Comments of the Participant*]
- Bemerkungen und Kommentare des Experimentators:
  [*Comments of the Experimenter*]