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The role of context in Müller-Lyer illusion: The case of negative Müller-Lyer illusion

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The Müller-Lyer illusion is one of the most prominent geometrical-optical illusions that have been the subject of experimental investigation throughout a century. Like most optical illusions the Müller-Lyer illusion is caused by an appropriate context - inward or outward fins that act in a specific manner. These fins either prolong or shorten the central line placed between the fins. In this study, we manipulated the context by varying the presentation of the illusion parts, which led to the negative effect of Müller-Lyer illusion. Here we disassociated the context, i.e., the fins that create the illusion, from the lines the length of which needed to be assessed. Firstly, the fins were presented alone for 10 seconds, than the line would appear alone for 100 ms. In such situations the phenomenon of illusion emerges in an opposite direction: the line that temporally succeeded the inward fins seemed longer, while the line succeeding the outward fins seemed shorter. An experiment with three experimental situations was carried out. Twenty participants took part in the experiment, in three different experimental situations. The size of the illusion was measured using the method of constant stimuli, which was also used to determine the point of subjective equality. The analysis confirmed the described effect which was found to be significant when compared to two other situations: the control situation and the standard Müller-Lyer illusion situation. The negative Müller-Lyer illusion is possibly caused by a kind of after effect, which occurred by prolonged gazing at the fins and/or by fatigue of the appropriate selective angle sensitive cells. Such findings implicate that angle sensitive cells might be active in the emergence of the standard Müller-Lyer illusion.

Key words: Müller-Lyer illusion, negative Müller-Lyer illusion, temporally disassociated presentation, figural after effect, angle selective cells

The majority of optical illusions are the result of the specific context manipulation of the critical part of the stimuli. There are different examples of how context distorts figures in a way that they might seem different in size, shape, or shade. In the particular case of the Müller-Lyer (ML) illusion, the critical part of the stimulus is the central line (shaft), while the fins represent the context that can modify the perceived length of the central line. The fins usually come in two forms: inward (<>), also called arrowhead, and outward (><), featherhead fins. The length of the central shaft, i.e., the line is overestimated when it ends in outward fins, or is underestimated when it ends in inward fins. The example of the ML illusion can be seen in Figure 1.

The ML illusion comes in several different variations. This illusion will also emerge if the double fins are replaced with single fins (e.g., Greene & Nelson, 1997). Furthermore, arches, squares, or circles replacing the fins will lead

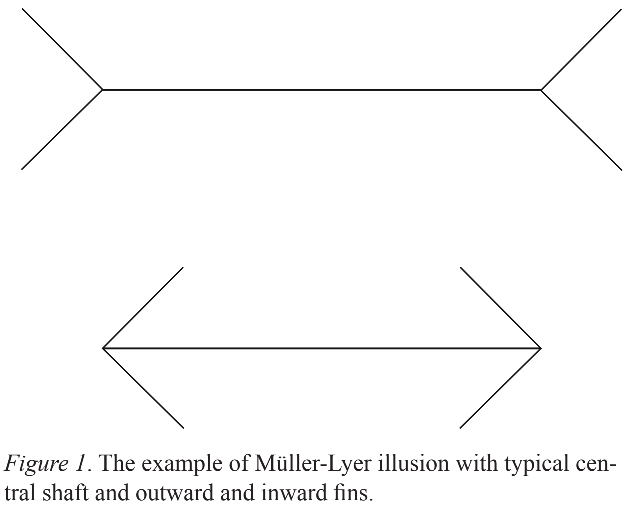

Figure 1. The example of Müller-Lyer illusion with typical central shaft and outward and inward fins.

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to the same effect (e.g., Howe & Purves, 2004). The illusion will manifest itself even if the central line is omitted: The space between outward fins will seem greater than the space between inward fins. Research on the topic of ML illusion date back to the beginning of the twentieth century. For instance, Judd (1902) demonstrated the effect of practice on the ML illusion. His participants were asked to estimate the size of the central line in 980 trials over the period of a few days. The results indicated that the strength of the ML illusion was reduced, and this the author attributed to practice. Although the ML illusion is aroused on simple principle, the interaction between central line and fins, that type of interaction is not yet understood.

The negative ML illusion was first identified phenomenologically. The authors noticed that when one is exposed to looking at the fins of the ML illusion for a prolonged period of time (e.g., 10 seconds or more) it can affect the perception of the lines whose presentation succeeds the presentation of the fins (see Figure 4). Interestingly, this effect seems to act in the opposite direction than the one in the standard ML illusion, which is the reason why this is labelled as "negative".

A review of the literature showed no record of the negative ML illusion except the work by Köhler and Fishback (1950a, 1950b), but the effect of the negative ML illusion was never studied in detail, or measured. Köhler and Fishback were intrigued by Judd's' work (1902) and wanted to find an alternative explanation for the reduction or possible destruction of the ML illusion. The authors concluded that practice was not the reason for the ML illusion destruction as stated by Judd (1902). They explained this phenomenon in terms of figural after effect, which was already of particular interest to Köhler (e.g., Köhler & Wallach, 1944). At that time, one group of theories whose main objective was the explanation of figural after effect applied to illusions emerged (Ganz, 1966; Köhler & Wallach, 1944). In these theories interference between nearby lines occurs because of satiation in the cortex or lateral inhibition processes. Figural after effect can be manifested in the shape and position distortions of the figures when the observer gazes long enough at the preceding figure. Köhler and Wallach (1944) offered an explanation for the figural after effect in accordance with gestalt teaching, i.e., in terms of electrical field theory, which they termed "satiation theory". According to them, the concept of satiation is explained by changes in the so-called electro-tonus. While gazing at the stimulus, these changes are manifested in the different electrical conductivity of the visual cortex. Osgood and Heyer (1952; in Osgood, 1953) criticized this explanation and offered a "statistical theory" that explains figural after effect in terms of the differences in activity distributions that occur when combining the activity distribution of observed stimuli and the previous stimulus. Fermüller and Malm (2004) reemployed statistics of visual computation in order to use mathematical models for prediction of geometrical optical illusions. They argue that the interpretation of image patterns is preceded by a step where image features such as lines, intersections of lines, or local image movement must be derived. In that process noise from different sources is present, and that noise causes bias. In return that bias is responsible for alternations in image perception. Furthermore, the authors argue that this bias is always present, and is part of uncertainty in our visual system. The illusory patterns are such that this bias is prominent.

In this paper we are not dealing with figural after effect explanation, but it seems that this phenomenon might play some role in the negative ML illusion emergence. Contemporary knowledge claims that different visual after effects are the result of the fatigue of specialized cells in the visual cortex while, simultaneously, the spontaneous activation of other specialized cells create the negative effect. In the perception of figures, feature detectors might play an important role in the origins of after effects. Köhler and Fishback (1950a, 1950b) could not predict the mechanism of feature detectors because the revolutionary work of Hubel and Wiesel (1959) on the subject of specialized cells in the visual cortex was published almost ten years later. Some of these detectors react to simple stimuli, lines and dots, while others react to more complex ones (angles, curves, and crosses).

Regardless of the theoretical explanation of the figural after effect mechanism, this seems like a suitable explanation for ML illusion weakening in condition of prolonged observing. If this is the case the figural after effect should have a similar effect on other illusions if the illusion context is manipulated in the same way (temporally disassociated presentation). However, the authors have carried out a phenomenological analysis on several other illusions and these observations showed that the after effect of temporally disassociated illusions result in the positive effect for the Ponzo and Hering illusion, and have no effect on Sanders and Poggendorff illusion. This raises the question as to why this negative effect is manifested in the ML illusion only.

The phenomenon of negative ML illusion could offer a new perspective on this illusion. In his work, Gregory (1968) listed numerous explanations for the ML illusion. Some of them have great historical but little scientific value. Gregory himself recommends depth theory as the best solution. According to his theory, fins create the illusion of depth that makes the central line appear either closer or more distant from the observer (Fischer, 1967; Gregory, 1963). Because of the size-constancy effect, the more distant line appears to be greater, as in the case of Ponzo illusion. However, it should also be noted that this explanation does not explain the case when the ML illusion is created using squares or circles instead of fins, or in the case when the central line is absent. Other explanations of the ML illusion include the confusion theory that claims that confusion about the place of the beginning and the end of central line is the reason for illusion emergence, as well as averaging theory (Erlebacher & Sekuler, 1969; Pressey, 1970) that claims that the perceived length of the central line is defined as the average of the real length and the length between the fin tips. The receptive field models (Walker, 1973) say that the size of proximal figures should determine the magnitude of distortions. Among these models emerges the idea that there are detectors for line orientation in the visual cortex. These detectors measure any orientation as the ratio of vertical to horizontal extent, which causes overestimation or underestimation of the outward or inward fins (Caelli, 1977). Later, that idea of oriented receptive fields is modified into idea of special frequency filters that is responsible for distortion in line length perception. Kawabata (1976) and Ginsburg (1984, 1986) offered an explanation for ML illusion that included filtering processes caused by lateral inhibition and which produce a certain amount of blurring of the retinal picture. However, this explanation failed to satisfy prediction in illusion effect as some other theories did, such as depth theory.

Another group of theories is related to feedback from efferent commands for eye movement (e.g., Judd, 1905; Kaufman & Richards, 1969). These theories suggest that perceptual distortions might occur because of inappropriate tendency to fixate the center of gravity of contextual figures when attempting to fixate the end of the focal shaft. However, results from different research suggest that simple straightforward explanation is not satisfactory and that there may be more than one simple mechanism contributing to illusion emergence. The aim of this study was to demonstrate the phenomenon of the negative ML illusion and to measure the magnitude of the effect of the negative ML illusion.

METHOD

Participants

Twenty psychology students (16 females) from the University of Zadar participated in this study. Their age span ranged from 18 years to 21 years, with a median of 19 years. All participants had normal or corrected vision.

Design

The experiment consisted of three experimental situations, a) standard ML illusion, b) a temporally disassociated ML illusion and, c) a control condition with two shafts that were in line with each other. Experimental situations were rotated using a Latin square rotation, one third of the participants began with the standard ML illusion, a second third of the participants began with the temporally disassociated ML illusion, etc. All participants took part in every experimental situation. The order of stimuli in every experimental situation was randomized for each participant.

Stimuli

The stimuli were arranged in order to represent the psychophysical method of constant stimuli. The standard stimulus (SS) was always presented on the left side of the computer screen, and on the left of the fixation cross that was presented on the center of the screen. The length of the standard line was set to 50 mm in all experimental conditions. The variable stimulus (VS) was always presented on the right side of the computer screen, on the right of the fixation cross, and varied in size. In experimental conditions with the standard ML illusion (see Figure 2) the illusion consisted of the usual parts: two lines, one with the inward fins and one with the outward fins. The size of the right variable stimuli, that is, the size of the line varied from 24-76 mm for 2 mm. In half of all situations, the standard stimulus was with inward fins, and in second half of all situations with outward fins. The preparation stimuli between the two experimental conditions lasted for 1500 ms and consisted only of the fixation cross. After 1500 ms the target stimuli appeared and lasted for 100 ms.

In the control situation the stimuli consisted of two black shafts that were in line with one another, one to the left of the fixation cross and one to the right of the fixation point. The standard left line was also set to 50 mm in all experimental conditions. The size of the variable line was set to vary in length from 40 to 60 mm, with a step of 2 mm. The length of the variable line was based on the results of preliminary research that showed that lines shorter or longer than 40 and 60 mm were not necessary, i.e., a line of 60 mm was estimated longer then line of 50 mm in all cases.

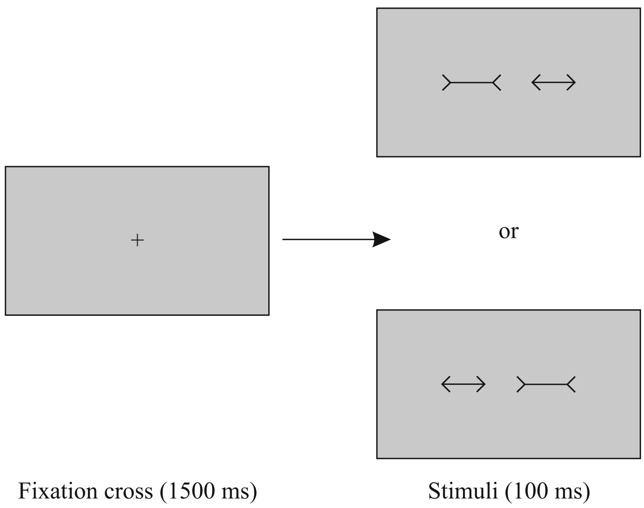

Figure 2. A presentation of the standard Müller-Lyer illusion. The left shaft was of fixed length and the right shaft varied in size. In half of all situations, the left stimulus was with inward fins, and in second half of all situations with outward fins.

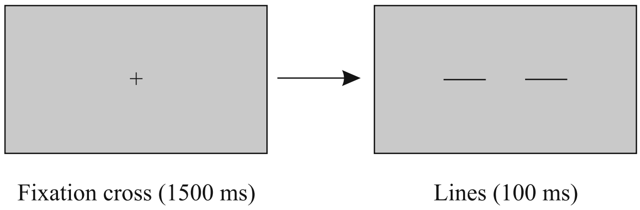

Figure 3. Control situation: The left line was of fixed length, and the right line varied in size.

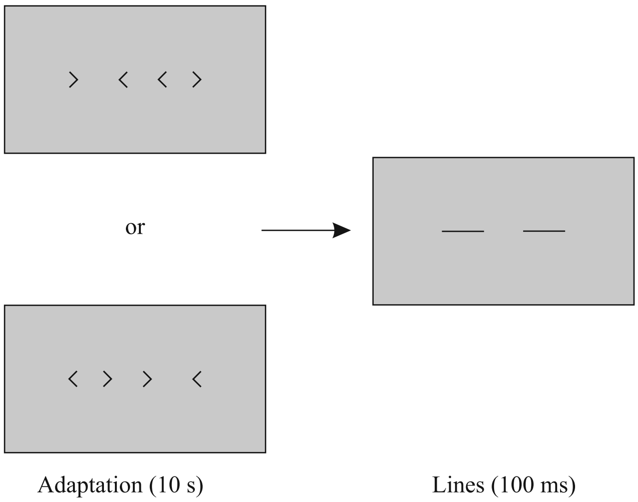

Figure 4. Temporarily disassociated presentation of the Müller-Lyer illusion. In half of all situations, the left stimulus was with inward fins, and in second half of all situations with outward fins. The left shaft was of fixed length, and the right shaft varied in size.

Moreover, the research would take too long to complete and the participants might experience fatigue. The preparations stimuli with the fixation cross lasted for 1500 ms, and afterwards the critical stimuli appeared for 100 ms (see Figure 3).

The third experimental condition that was crucial for this experiment dealt with the temporally disassociated ML illusion (see Figure 4), i.e., the shaft and fins were not present on the screen simultaneously. Firstly, the fins would appear on the left and the right hand side of the screen for a period of 10 seconds, and later only two shafts would appear that fitted the previously presented fins. The shafts were presented for only 100 ms where the left shaft was fixed to the length of 50 mm and the right shaft varied form 24 to76 mm. In order to avoid the expectation of line length only shafts varied in length, while the fins were held constant and were always in an equal distance of 50 mm.

Materials and procedure

The stimuli were presented on a CRT 17” monitor with the refresh rate of 80 Hz. The procedure followed the method of constant stimuli for measuring the differential threshold. The participants’ task was to press either the right or the left button depending on which shaft they considered to be the longer one. The size of variable stimuli changed randomly. There were 20 series for control and the standard ML situation and 16 series for the temporally disassociated ML illusion. As mentioned earlier, the second experimental situation required the prolonged gazing at fins that might cause eye fatigue, therefore a series of 16 situations was considered optimal. Testing lasted for 90 minutes with pauses.

RESULTS

From the series of answers the point of subjective equality (PSE) for each participant in every situation was calculated. The size of the illusion effect can be expressed using the PSE value. This is the value where the participant subjectively equalizes the variable stimulus with the standard stimulus. It was calculated using the equation from the *Experimental Psychology of Sensory Behavior* (Corso, 1967).

$$PSE = S_b + \frac{(S_a - S_b)(C - p_b)}{p_a - p_b}$$

PSE – point of subjective equality

S_a, S_b – stimulus value immediately above the upper and below threshold

C – the proportion of judgments defining the PSE criterion (C = .5)

p_a , p_b – the proportion of “higher” and “lower” judgment for the stimulus value immediately above or below the corresponding threshold

In data analysis both the standard and the negative ML illusion were compared to the control condition, separately for the inward and the outward fins condition, which makes a total of five conditions. All five conditions were tested in one-way repeated measures ANOVA, which showed a statistically significant effect, $F(4, 76) = 406.77$, $p < .001$. The post hoc analysis (Fisher LSD) showed significant differences between all five conditions ($p < .05$). It is important to note that all four experimental conditions are significantly different from the control condition, and that the effects obtained in the negative ML conditions are opposite to those in the standard ML condition. These effect directions can be seen in Figure 5 when comparing graph values to the dotted line that indicates the magnitude of the standard stimulus. In the negative ML illusion conditions with inward fins, the shaft was perceived to be longer, and in the condition with outward fins it was perceived to be shorter. On the contrary,

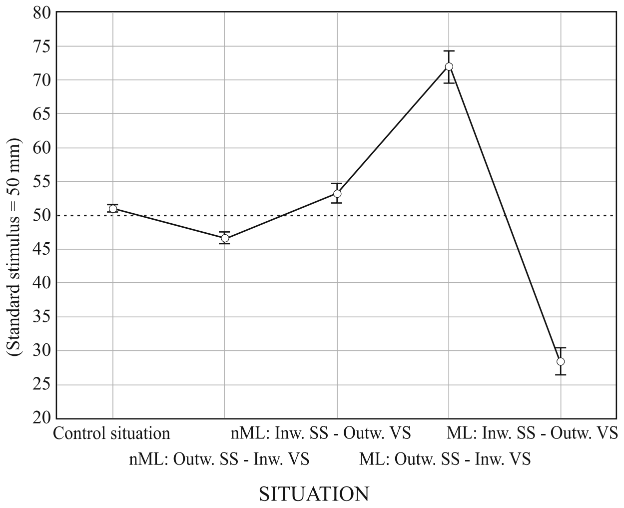

Figure 5. The comparison of the control and four experimental conditions. Two of them illustrate the effect of the negative Müller-Lyer illusion (nML), while the last two illustrate the classical Müller-Lyer (ML) illusion. The variable stimulus (VS) was always compared to the standard stimulus (SS). Inw. = inwards fins; Outw. = outward fins.

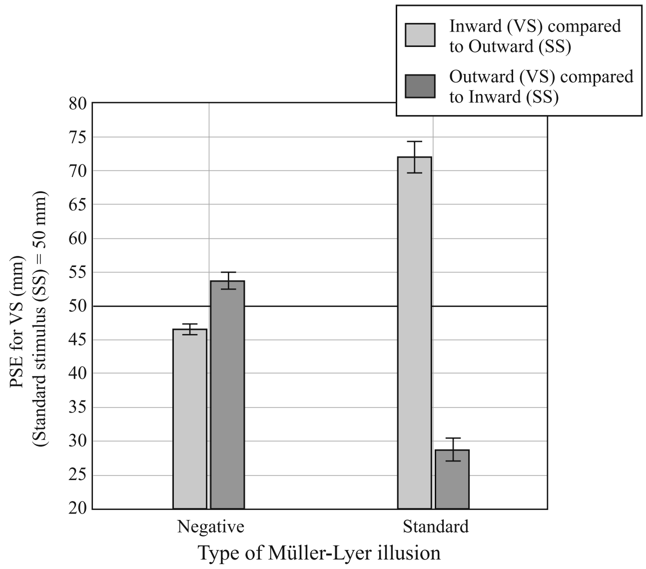

Figure 6. A comparison of the negative and the standard Müller-Lyer illusion in two conditions, with the inward fins or the outward fins as a variable stimulus (VS) compared to the standard stimulus (SS) of 50 mm.

the inward fins caused shaft to be perceived as shorter, and the outward fins caused it to be perceived as longer in the standard ML condition. As seen, this effect is in the opposite direction of the expected standard ML illusion effect. Thus, this indicates the existence of the negative ML illusion.

The stimuli with inward fins work in a direction of decreasing the central line, while stimuli with outward fins work in a direction of increasing the central line. In the upcoming analysis we will present a comparison of the standard and the negative ML illusion effect, as well as the effect size of each illusion.

The two-way repeated measures ANOVA showed a significant interaction effect, $F(1, 19) = 610.38$, $p < .001$, for the ML illusion type, and for the fins orientation (see Figure 6). Moreover, the post-hoc analysis (Fisher LSD) showed significant differences between all four situations ($p < .001$). This finding demonstrates not only the significance of the effect on both illusions, but also the significance of the opposite effect for the negative and the standard ML illusion.

In the last part of the analysis, absolute values for the effects size of the ML illusion, the standard and the negative one, were calculated. For calculating the size effects we used the equation proposed by Bruno, Bernardis, and Gentilucci (2008). According to procedure, absolute effects of the illusions were calculated, and were expressed as the percentage of the basic line that was defined by a standard stimulus of 50 mm. The sizes of the illusions were compared (see Figure 7). The average value of the negative ML illusion is 6.63% ($SD = 2.92$), while the average value of the standard ML illusion is 43.28% ($SD = 8.22$). Using one-way repeated measures ANOVA, both results were analyzed in contrast to the average error in the control situation (2.34%, $SD = 1.60$). The tested difference between situations was significant, $F(2, 38) = 426$, $p < .001$. The post hoc analysis (Fisher LSD) showed significant differences between all three tested situations ($p < .01$). The absolute effect of the standard ML illusion is significantly greater than the negative ML illusion and the control situation. The absolute ef-

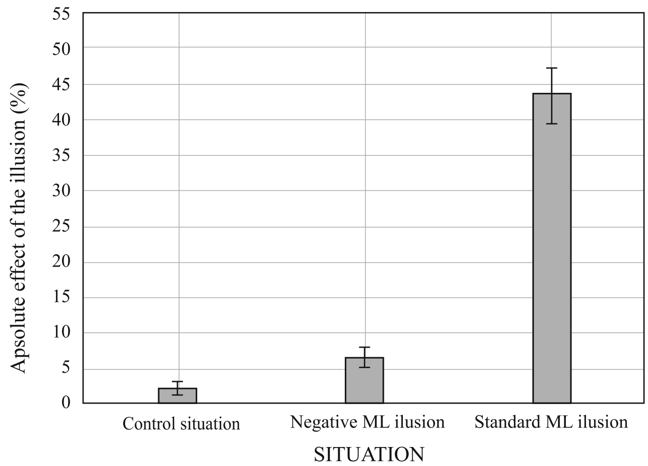

Figure 7. The absolute magnitude of the negative and the standard Müller-Lyer illusion.

fect of the negative ML illusion is significantly greater than the control situation.

DISCUSSION

The main goal of this study was to demonstrate and measure the size of the negative ML illusion, as well as to compare it to the standard ML illusion. The phenomenon of the negative ML illusion has been proved and measured. The effect of the ML illusion was significant when compared to the control situation, and was also less than the standard ML illusion. Moreover, the effect of the opposite direction compared to the standard ML illusion was proven.

In order to elicit the negative ML illusion one must manipulate the context in a different manner. The negative ML illusion manifests itself in the "temporally disassociated" condition of the standard ML illusion, where the context is temporally disassociated from the critical part of the stimuli. This results in distortion in the line length in the observer's perception. However, this distortion is in the opposite direction than one would expect in the standard ML illusion. The line that was placed where inward fins were previously placed seemed to be longer, while the line that placed where outward fins were previously placed seemed shorter.

The contemporary research on the topic of ML illusion usually use ML illusion as a tool to investigate models of human vision, in particular proposed division between vision-for-action (identified with the V1-PPT dorsal stream) and vision-for-perception (the V1-IT ventral stream). This model is good at predicting broad range of behavioral and neuropsychological data, but what remains controversial is why visually guided action is immune from visual illusions (Bruno et al., 2008; Thompson & Westwood, 2007). In another words, researchers are more interested in illusion destruction especially when the action is involved. Further debate on this topic aims to isolate motor responses from conscious perception (Bruno, Knox, & de Grave, 2010). This resulted in revival of the theories of eye movement as a source of the illusion emergence, as well as efferent theory that describes a dynamic interaction of the responses on stimulus perception (Honda, 1985, 1990). However, in their meta-analysis Bruno et al. (2010) showed that the size of the illusion effect on saccades showed a large variability, ranging from 30% to less than 10%. This indicates that there are other factors modulating the size of the illusion besides mere responses mode (perceptual or motor). Moreover, the theory of eye movement, and occulomotory feedback is aplicatory in this research because of stimuli presentation, where participants were instructed to gaze at fixation cross, and afterwards lines were presented in tachitoscopic manner.

The effect of negative ML illusion elicited in this study points to several things that might prove crucial for a better understanding of the ML illusion. First of all, the negative ML illusion is apparently based on the mechanism of after effect. It is possible that gazing at the fins for a prolonged period of time causes the after effect that leads to the delusional effect which is in the opposite direction to the length of the central line. Furthermore, the fins or arrows in the ML illusion can be seen as angles that have a corresponding orientation and position. By using the technique of single cell recording on macaque monkeys it has been found that the representation of stimuli complex features begins in the visual cortex in the V2 area (Ito & Komatsu, 2004; Kobatake & Tanaka, 1994), and continues to spread via the ventral visual pathway to the V4 area. These complex visual features include angles of different sizes and different orientations. Ito and Komatsu (2004) found that selective cells in the V2 area are not so selective, meaning that even though these cell are activated by angles, they also became activated when looking at single lines of the same orientation that form a part of angle. In the V4 area more selective cells were found that react to complex features of stimuli, including the angles (Kobatake & Tanaka, 1994). These cells are more specialized and more sensitive to the whole angle orientation, but are not sensitive to orientation of single lines, which means that these cells represent angles more elaborately. As in the case of other after effects mechanisms, it is possible to put specialized cells in a temporary state of fatigue. When this occurs the spontaneous activation of other cells is greater than when compared to those in a state of fatigue, which causes the opposite effect. There are many known examples. For instance, adaptation to red color stimuli will cause a green after effect. Furthermore, adaptation to angled lines causes an after effect that makes seemingly vertical lines angled in a different direction. Adaptation to the movement of stimuli in one direction will cause the after effect of the movement of still stimuli in the opposite direction (see Mather, Verstraten, & Anstis, 1998). Adaptation to a specific spatial frequency grid will cause a lower sensitivity to the corresponding spatial frequency grid (McCollough, 1965). In accordance with this, one can assume that the adaptation to angles of specific orientation might cause an illusory greater activity of the opposite angle orientation detectors. Such activity can cause short-termed distortion of the line length in the same way as actual angles do in the standard ML illusion.

The evidence suggests that the underlying cause of the ML illusion does not lie in multiple processes, as stated in the theory of perspective/depth (Gregory, 1963; Fischer, 1967). As depth theory has been proved as an unsuitable explanation for the ML illusion, later findings (Dragoi & Lockhead, 1999) suggest a population model of orientation detectors in the visual cortex that explain their obtained results for ML illusion as a byproduct of the orientation and distance effect of long-range horizontal cortical connections. Their starting point is the idea that human visual system decomposes an image using local filters tuned for stimulus features, such as spatial frequency or orientation. Furthermore, psychological evidence suggests that the local filters are not independent, but they receive input from neighborhood spatial frequency or orientation filters. Dragoi and Lockhead (1999) argue that this network of long-range interconnections may serve as substrate for context dependency. In other words, context dependency means that the perceived features of the stimulus depend on context surrounding it. In their research the confirmations for such suggestion was obtained.

However, we suggest that feature detectors specialized for angles are the one that may play an important role in the ML illusion. These features detectors are activated in the standard ML illusion and their after effect is active in the negative ML illusion. These specialized cells can be referred to as neural filters. However, the mechanism how the standard ML illusion changes into the negative one is still on the level of speculation and requires further systematic investigation.

Furthermore, it is possible that the position of the angle in the visual field is perceived by an imaginary placed position that is located inside the angle, rather than one placed on the starting point of the angle. This assumption is in line with the claim of uncertainty that arouses in visual system due to bias (Fermüller & Malm, 2004). However, this assumption also requires further investigation. If this proves correct, the imaginary position in the visual field that represents the angle can make a move in the angle focus on the line in the inward condition and behind the line in the outward condition. Also, this might be the reason why the inward fins make the line seem shorter, and the outward fins make it seem longer. This proposed explanation is consistent with the confusion theory of the ML illusion emergence, which suggests that the perceptual system miscalculates the location of the arrowhead vertex, displacing it toward the concave side (Chiang, 1968). Furthermore, Chiang's (1968) theory applies to patterns in which lines running close together affect one another. Two close lines influence each other's location and become one when the sum of their distribution of activation on retina forms a single peak. This leads to an overestimation of acute angles, and provides explanation of the ML illusion, as well as the Poggendorff and Zöllner illusion. Confusion theory can explain most of the known variations of the ML illusion, e.g., when the lines are bordered with squares of circles. In the last two examples of the ML illusion the position of the bordered object is placed within that object.

One should not neglect the possibility that the ML illusion emerges because of a more general figural after effect as discussed by Köhler and Wallach (1944) or Osgood and Heyer (1952; in Osgood, 1953). But then it remains unclear when considering all „temporally disassociated" illusions only the ML illusion shows a pattern of this negative effect. On the other hand, the Ponzo and Hering illusion are two illusions that most probably emerge because of the experience of perspective, i.e., depth. In the phenomenological effect verification of the Ponzo and Hering temporally disassociated illusions, distortion had a positive, not a negative effect. It can be assumed that the illusions that emerge from the perceptive processes that are based in the impression of depth are not subject to this after effect. Furthermore, the ML illusion is influenced by the negative after effect and therefore probably does not emerge from the same mechanisms as the Ponzo illusion does.

In conclusion, this study demonstrates the existence of the negative ML illusion that has the opposite effect when compared to the standard ML illusion. This effect is a short-termed and weaker one than in the standard version of this illusion, but is still significant. The underlying cause of the negative ML illusion is probably some kind of negative after effect, and it is possible that the direction of this illusion emerges because of the fatigue of the cells specialized for angles of specific orientation. If this is the case, than it can be assumed that the same process is the underlying cause of the standard version of this illusion, i.e., this illusion could be the result of the activation of the cells that are specialized for selective angles. The same explanation might be applicable to variation of the ML illusions when the central line is not placed between angles, but between arches, squares, or circles.

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