Shape constancy, not size constancy: A (partial) explanation for the Müller-Lyer illusion

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Abstract

The Müller-Lyer illusion is one of the best-known and most frequently examined optical illusions. After pointing out that it is unlikely that any one account would give a full explanation for all the features of this illusion, I argue for two claims. First, I aim to point out that an essential component of the Müller-Lyer illusion has something to do with picture perception (just as Gregory initially claimed). Second, I give an account of this essential component of the Müller-Lyer illusion that is not susceptible to the counterexamples and objections Gregory's inappropriate size constancy scaling theory was susceptible to. The gist of my account is that the Müller-Lyer illusion is explained not by inappropriate *size* constancy scaling, but by inappropriate *shape* constancy scaling.

Keywords: size constancy, shape constancy, picture perception

The Müller-Lyer illusion consists of two lines of equal lengths. We know that they are of equal length, but we cannot help perceiving one as longer than the other. There are several popular and less popular explanations for this phenomenon, none of them uncontroversial. I argue that if we modify the most popular account of explaining this visual illusion, Richard Gregory's 'inappropriate constancy scaling' theory, we may be able to explain many (but not all) important features of this dimension. But this modification will be a substantive one: instead of inappropriate *size* constancy scaling, the Müller-Lyer illusion is (partially) explained by inappropriate *shape* constancy scaling.

The inappropriate size constancy scaling theory

Perhaps the most popular explanation for the Müller-Lyer illusion was given by Richard Gregory (Gregory, 1963; 1966; 1968). He claims that the two lines of the Müller-Lyer illusion are "flat projections of typical views of objects lying in three dimensional space" (Gregory, 1963, p. 678). In other words, the experience of the Müller-Lyer illusion is intricately connected to picture perception: the perception of three dimensional objects in two dimensional surfaces.

It is not entirely clear what the exact relation between the experience of Müller-Lyer illusion and picture perception is supposed to be in Gregory's theory. It seems that he has two logically independent explanations that he often uses interchangeably, without explicitly differentiating between the two. They are the following:

(a) When we experience the Müller-Lyer illusion, we literally see three dimensional objects (or at least three dimensional features) in the two dimensional surface
(b) When we experience the Müller-Lyer illusion, we do not see a three dimensional object in the flat surface, but we are aware of, and mislead by, certain cues that are typically associated with the perception of three dimensional objects.

Although these two versions of the inappropriate size constancy scaling theory seem very different indeed, Gregory never differentiated them explicitly and he often wrote as if the two hypotheses were really the same. Version (a) and (b) are both present in Gregory, 1963, but later formulations put the emphasis on (b). Depending on which version we choose, Gregory's appeal to inappropriate size constancy scaling will also be slightly different.

If, as in version (a), we literally see two three dimensional figures when we experience the Müller-Lyer illusion, we see the convex edge of a three dimensional object in the line with arrow junctions and we see the concave edge of a three dimensional object in the line with fork junctions. Further, we perceive the concave edge to be further away than the convex edge. And, as the two edges are perceived as being of different distance, their size is also experienced differently: "The parts of the figures corresponding to distant objects are expanded and the parts corresponding to nearer objects are reduced" (Gregory, 1963, p. 678).

If we consider version (b), the explanation will be slightly different. We do not see anything three dimensional when we are looking at the Müller-Lyer illusion, so the inappropriate size constancy scaling cannot be triggered by the perception of objects that are of different distance from me. But we do perceive cues that we normally encounter when we see three dimensional objects and the experience of these cues is what triggers the inappropriate size constancy scaling. We are used to perceiving three dimensional objects, among them convex and concave edges of houses and rooms. When we see the Müller-Lyer illusion, we are mislead by cues that we normally encounter when looking at convex and concave edges of houses and rooms. And these cues trigger inappropriate size constancy scaling because we are used to certain size constancy scaling when seeing a concave edge and we are used to a different size constancy scaling when seeing a convex edge. Thus, the inappropriate size constancy scaling is triggered without the experience of anything three dimensional and without the experience of distance, purely by depth cues.

Which of the two versions are more convincing? After the initial ambiguity between the two versions, Gregory seems to have settled for (b), and although he never addressed the respective advantages of the two versions, an important consideration for version (b) of the inappropriate constancy scaling theory is Irwin Rock's influential criticism of Gregory's original account (Rock, 1975). Rock argues that even if we grant that we perceptually interpret the line with arrow junctions as a convex corner and the line with fork junctions as a concave corner, there is no reason to suppose that we perceive the convex corner to be closer than the concave one. But inappropriate constancy scaling is triggered only if these two are perceived to be of different distance. Hence, Gregory's explanatory scheme is missing an important step. And he concludes accordingly: "the Müller-Lyer illusion is generally not seen as three-dimensional" (Rock, 1975, p. 412).

Note that this objection only applies in the case of version (a) of the inappropriate constancy scaling theory. It is only version (a) where the Müller-Lyer illusion is seen as three dimensional. Thus, if we are moved by Rock's objection but want to preserve the spirit of the inappropriate size constancy scaling theory, we could dispose of version (a) and settle for version (b), which is arguably exactly what Gregory has done.

It needs to be noted that version (b) is not unproblematic either. Rock pointed out in the case of version (a) that we have no reason to suppose that the two edges are perceived to be of different distance. But an analogous worry could be raised about version (b). What reason do we have to suppose that the two lines are perceived as containing three dimensional cues? And even if they are, what reason do we have to suppose that the two lines are perceived as containing three dimensional cues that trigger inappropriate constancy scaling? Thus, it seems that neither version (a) nor version (b) can explain those aspects of the Müller-Lyer illusion that Gregory set out to explain.

Alternative explanations

Irwin Rock's criticism of Gregory's account was one of the first objections in a series of objections against the inappropriate size constancy scaling theory. It is virtually impossible to enumerate all objections, and I will return to some of these at the end of the paper. But for now it is enough to note that these objections opened the way for alternative explanations of the Müller-Lyer illusion. While the 'inappropriate constancy scaling theory' appealed to fairly higher order cognitive processes (such as the recognition of three dimensional cues or picture perception), these alternatives usually aim to explain the Müller-Lyer illusion in terms of lower order processes, such as eye movement (Festinger et al., 1968, but see Pritchard, 1958), tilt constancy theory (Prinzmetal et al., 2001, but see Wenderoth & Burke, 2006) or selective filtering (or, low pass spatial filtering, see Ginsburg, 1984, also Coren & Girgus, 1976).[1]

Irwin Rock's positive account is known as the 'incorrect comparison theory': when we experience the Müller-Lyer illusion, what we really compare is not the size of the two vertical lines, but rather the size of the whole figure (Rock, 1975, p. 313ff, the idea goes back to Woodworth, 1938, p. 645). This hypothesis is supported by the observation that if the shaft has a different color, the illusion is not so pronounced (Coren & Gingus, 1972).

Rock's account is similar to R. H. Day's very early alternative to Gregory's explanation (Day, 1972a; 1972b; Degoldi & Day, 1992). Day argues that the explanation of the Müller-Lyer illusion is similar to that of the Ebbinghaus illusion (where a circle surrounded by larger circles looks smaller than a circle of the same surrounded by smaller circles), the Deloeuf illusion (where two circles of the same size look to be of different size depending on whether there is a circle inside or outside of them) or the simple phenomenon that a passage on a large empty page seems smaller than it would be if the paper were cropped immediately under and below it. One explanatory advantage of Day's explanatory scheme is that it could explain the existence of the Müller-Lyer illusion in the haptic sense modality (Day, 1965), as the haptic sense modality is as sensitive to the contrast of the surrounding features as the visual one. I will return to the discussion of the haptic Müller-Lyer illusion at the end of the paper.

Evaluating all the alternative explanations of the Müller-Lyer illusion would take a book-length study. Further, we have no reason to suppose that the Müller-Lyer illusion can be fully explained by any one of these accounts. A number of factors contribute to this illusion and Rock's account may well capture one of these factors. The aim of this paper is to single out an important factor that also contributes to the illusion: the one that Gregory wanted to capture and that has something to do with picture perception and to give an unproblematic account of this one factor only. This account would not provide a complete explanation for the Müller-Lyer illusion, but only a partial one.

There are important aspects of the illusion that are not explained by any of the existing accounts. For example, it has been pointed out that the illusion decreases in microgravity, which seems to indicate that the illusion is not fully explained in terms of the (mal)functioning of our visual perceptual apparatus only (Villard et al., 2005). No existing explanation of the Müller-Lyer illusion can account for this difference. Some other odd features of the illusion that any account should be able to at least address, if not fully explain, include (but are not limited to) the fact that the Müller-Lyer illusion is experienced in the haptic sense

[1] Other, more 'higher order' explanations include the 'latency correction theory' (Changizi & Widders, 2002) and the 'figure ground organization theory' (Taya & Ohashi, 1992).

modality and that it is also experienced by some non-human animals. I will return to these odd features at the end of the paper.

We have good reason to suppose that there are a number of factors that contribute to the Müller-Lyer illusion. Hence, instead of trying to find a monolithic explanatory scheme, the best we can do is to single out, and explain, the most important ones of these factors. This is exactly what I aim to do here.

Thus, the structure of my argument is the following. First, I aim to point out that an essential component of the Müller-Lyer illusion has something to do with picture perception (just as Gregory initially claimed). Second, I give an account of this essential component of the Müller-Lyer illusion that is not susceptible to the objections Gregory's inappropriate size constancy scaling theory was susceptible to.

Picture perception and the Müller-Lyer illusion

My claim is that any explanation of the Müller-Lyer illusion that ignores the connection between this illusion and picture perception misses out on an essential component of this illusion. In other words, at least one mechanism that is essentially responsible for the Müller-Lyer illusion is also the one that helps us to see three dimensional objects in two dimensional pictures (see also Redding & Hawley, 1993).

Some initial support for these claims comes from studies of patients who do not experience the illusion. Patients suffering from visual agnosia, for example do not experience the illusion (Turnbull et al., 2004). As these patients are also notoriously bad at seeing objects in pictures, this finding is at least indicative of the connection between the Müller-Lyer illusion and picture perception. Further, it has also been pointed out that the illusion also breaks down if the superior (and inferior) parietal cortex is damaged, an area usually involved in three dimensional objects perception (Weidner & Fink, 2006). As left visuospatial neglect patients still perceive the illusion (although the illusion is somewhat weaker in their case, see Mattingley et al., 1995), this also indicates that the experience of the Müller-Lyer illusion presupposes the ability to perceive three dimensional objects.

However, I only take these findings to be indicative of the connection between picture perception and the Müller-Lyer illusion. Here is a more direct connection. If it is true that our experience of the Müller-Lyer illusion is based on seeing a three dimensional figure in the line drawings, then the illusion is bound to diminish if we force our perceptual apparatus to interpret the line drawings as a *different* three dimensional object. This is what the following modification of the illusion is supposed to achieve:

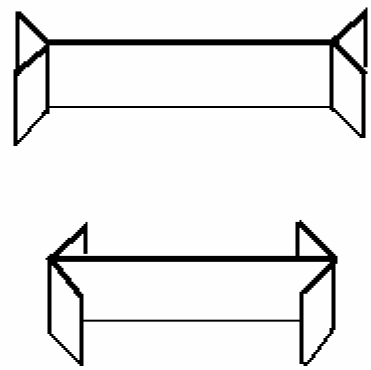

Figure 1.

Compare the length of the two rectangles. Although the illusion does not disappear completely (arguably for the 'incorrect comparison' reasons noted by Rock, 1975), it diminishes significantly. This phenomenon would be very difficult to explain without any appeal to picture perception. If, however, we assume, like Gregory did, that our experience of the Müller-Lyer illusion presupposes our experience of two different three dimensional figures in the two line drawings, we can explain why the illusion diminishes significantly in this case. Our perceptual system is forced to interpret the two original line drawing figures as part of a *different* three dimensional object (the three dimensional walls of a Müller-Lyer illusion shape): thus, it cannot interpret the two original line drawing figures as a convex and a concave edge.[2]

These considerations could be used to support version (a) of Gregory's inappropriate size constancy scaling theory as this account posits a necessary connection between the Müller-Lyer illusion and picture perception. But they equally support any theory that makes a necessary connection between the Müller-Lyer illusion and picture perception and Gregory's theory is not the only possible account (and maybe not even the most plausible account) that does so. I aim to outline an alternative to Gregory's inappropriate constancy scaling theory that still uses picture perception as a starting point.

[2] It has been argued that shading that is used to emphasize the three dimensional visual interpretation of the two lines (as convex and concave edges) does not increase the illusion (Zanker & Abdullah, 2004). This finding is inconclusive as, provided that the perceptual system already interprets the lines as depictions of three dimensional figures, we should not expect that adding shading would make the perceptual system interpret the lines as *more* three dimensional. The argument I give in this section could be thought of as following the exact opposite strategy: I argue that adding three dimensional cues that makes the perceptual system interpret the lines to be depictions of *different* three dimensional figures *decreases* the illusion.

Inappropriate shape constancy scaling

Let us begin with one of the earliest demonstrations of shape constancy (Thouless, 1931a; 1931b; 1933). If we look at a coin from an oblique angle, our experience of its shape is an intermediate shape between the shape projected on our retina and the coin's real (round) shape. As Robert Thouless put it in 1931, "under ordinary conditions of binocular vision, the actually experienced character of the object (or the 'phenomenal character') is a compromise between the 'real' character of the object and the character given by peripheral stimulation, […] the phenomenal character shows a tendency away from the stimulus character towards the 'real' character of the object" (Thouless, 1931a, pp. 343-344). Although there have been some worries about the methodology Thouless used and about the scope of his claims, the general proposal that experienced shape is somewhere between the shape projected on the retina and the shape of the object has not been questioned (see Epstein & Park, 1963 for a summary). Let us now apply this observation to rectangles and trapezoids (rather than circles and ovals):

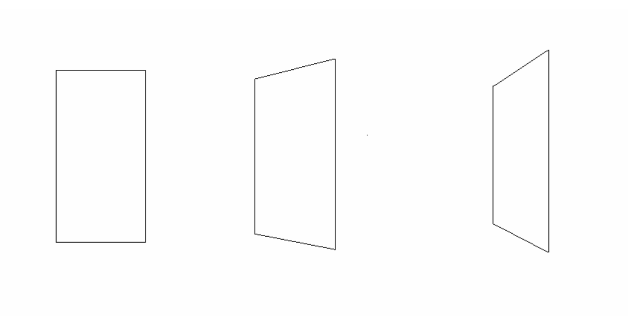

Figure 2.

If the shape on the right is projected on our retina, then, because of shape constancy, the experienced shape will be somewhere between the shape on the left, the 'real' shape (rectangle) and the shape on the right, the shape projected on the retina. It will be something like the shape in the middle.

Now think of the two lines of the Müller-Lyer illusion as two figures both consisting of two identical trapezoid shapes.[3] The line with arrow junctions consists of two trapezoid shapes that share their longer parallel line and have their shorter parallel line missing. The line with fork junctions, in contrast, consists of two trapezoid shapes that share their shorter parallel line and have their longer parallel line missing.

If it is true that the experienced shape of these trapezoid shapes is corrected by the perceptual system to be more similar to the 'real' rectangular shape, then the longer parallel line of these trapezoids is experienced as shorter than its retinal projection and their shorter parallel line is experienced as longer than its retinal projection. But remember that the line with arrow junctions consists of two trapezoid shapes that share their longer parallel line and have their shorter parallel line missing. Thus, as these trapezoid shapes are experienced in such a way that the longer parallel line is shorter than its retinal projection, the line with arrow junctions is experienced as shorter than its retinal projection. Conversely, remember that the line with fork junctions consists of two trapezoid shapes that share their shorter parallel line and have their longer parallel line missing. Thus, as these trapezoid shapes are experienced in such a way that the shorter parallel line is longer than its retinal projection, the line with fork junctions is experienced as longer than its retinal projection.

In other words, the two lines of the Müller-Lyer illusion are in fact experienced as two dimensional depictions of three dimensional figures: of a concave and a convex edge. But we do not experience one of these edges to be further away than the other. Rock correctly pointed out that we have no reason to suppose that we experience the convex edge to be closer to us than the concave one. Hence, we have no reason to suppose that our explanation of the Müller-Lyer illusion is based on inappropriate size constancy scaling.

But if we explain the Müller-Lyer illusion with the help of inappropriate shape constancy scaling, we do not have to make the dubious assumption that we perceive the two edges as being of different distance. According to the inappropriate shape constancy scaling account, we do experience the two lines as two dimensional depictions of three dimensional figures: of a concave and a convex edge, but we do not perceive one of them to be closer than the other.

It is important to emphasize this point as one may wonder how different the new shape constancy scaling account really is from Gregory's original size constancy scaling account. The answer is that it is very different. According to the size constancy scaling account, we represent the concave edge as being further away from us than the convex edge. And Rock powerfully argued against this assumption. The shape constancy scaling does not entail that we represent that concave edge as being further away from us than the convex one. We represent the rectangles as being tilted in space; we represent them as three dimensional objects, but we do not represent one of them as being further away than the other in order to experience the illusion. The account I outlined here avoids Rock's influential objection.

The inappropriate shape constancy scaling account can also explain, or at least be taken to be consistent with, at least some of the odd features of the Müller-Lyer illusion. The illusion is more pronounced if we increase the length of the arrows at the end of the two lines. It is not clear how Gregory's inappropriate size constancy scaling account can give a robust, and not *ad hoc*, explanation for this. The inappropriate shape constancy scaling account, in contrast has a simple explanation: the longer the arrows are the

[3] Fisher, 1967 suggested something similar when trying to give a combined explanation for the Ponzo and the Müller-Lyer illusion.

longer the non-parallel sides of the two trapezoid shapes will be. And the longer the non-parallel sides the two trapezoid shapes are, the more difference the shape constancy scaling makes to the length of the parallel sides of the trapezoids (e.g., if the non-vertical lines in Figure 2 are longer, the difference between the vertical lines is larger).

It has been argued as early as Gregory's initial explanation that the Müller-Lyer illusion is stronger among Europeans than among African populations (Segall et al., 1963, see also Deregowsky, 1974; Gregory, 1963, p. 680). Further, in a later and more comprehensive study, it was argued that within Zambia, people living in cities were more susceptible to the Müller-Lyer illusion than those living in rural environments (Steward, 1973, see also Leibovitz et al., 1969). This finding is consistent with the inappropriate shape constancy scaling account and, to a certain degree, it can even be explained by it. If one of the major factors that cause the Müller-Lyer illusion is the inappropriate shape constancy scaling of rectangles, then what we should expect is that those people who have been perceptually less exposed to rectangles are less susceptible to the illusion. We know that the strength of shape constancy varies with exposition to various shapes (Myambo, 1972), if it is true that one of the major factors that cause the Müller-Lyer illusion has to do with shape constancy, we should expect the same in the case of the Müller-Lyer illusion.

Another odd feature of the Müller-Lyer illusion is that it is also experienced in the haptic sense modality. If we are allowed to touch two objects with the shape of the two lines of the Müller-Lyer illusion, without looking at them, we experience the same illusion (Heller et al., 2002, the observation goes back to Revesz, 1934). This finding does not falsify the account I outlined here, as we could appeal to visualizing on the basis of our tactile experiences of the two lines when explaining the haptic illusion (Frisby & Davies, 1971, but see also Over, 1967; Suzuki & Arashida, 1992).

Even more disturbingly, even blind, further, even congenitally blind people can experience the haptic Müller-Lyer illusion (Heller et al., 2005). Here, the defender of the explanatory scheme I defended above could still appeal to visualizing, as there is evidence that at least some blind (and even some congenitally blind) people are capable of visualizing or at least of having visual imagery (see Aleman et al., 2001; Hollins, 1985). Thus, they are still capable of visualizing the illusion on the basis of their tactile experiences.

Some may find the appeal to visualizing on the basis of haptic experiences slightly problematic it is important to point out that this explanatory scheme does not form an essential part of the inappropriate shape constancy scaling account. As I emphasized above, the inappropriate shape constancy scaling is not intended to provide a full explanation for all features of the Müller-Lyer illusion. It is intended to provide an explanation for a major factor that contributes to the illusion, but there may be (and there presumably are) other factors. Irwin Rock's 'incorrect comparison theory' may capture one of these. And Rock's 'incorrect comparison theory' seems to be able to explain the presence of the illusion in the haptic sense modality: the haptic sense modality is as sensitive to the contrast of the surrounding features as the visual one (see Day, 1965 for a similar explanatory scheme).[4]

Yet another odd feature of the Müller-Lyer illusion is that it is also experienced by pigeons (Nakamura et al., 2006). Although this finding may sound disquieting for the advocate of the inappropriate constancy scaling accounts, as these accounts use relatively higher order cognitive processes for explaining the illusion and one may wonder whether pigeons are capable of such higher order cognitive processes.

But the situation is not so dramatic (interestingly, even Rock cautions against drawing far reaching conclusions from these findings, see Rock, 1975, p. 440). It has been suggested that pigeons are also capable of picture perception (Fagot, 2000). If so, however, then pigeons have all the cognitive apparatus that, according to the account outlined here, is needed for the experience of the Müller-Lyer illusion. The seemingly surprising finding that pigeons also experience the Müller-Lyer illusion indicates that the inappropriate shape constancy scaling account I defended in this paper is at least on the right track.

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[4] Rock's 'incorrect comparison theory' also fares better at explaining those versions of the illusion where at the ends of the two equal lines the arrows are replaced by circles or squares (the examples come from Day 1972a).

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