

Are size illusions in simple line drawings affected by shading?

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Abstract. In a number of simple line drawings, such as the Müller-Lyer or Judd figures, we can experience strong distortions of perceived space—geometric illusions. One way of explaining these effects is based on the perspective information that can be read from the line drawings. For instance, the ‘inappropriate constancy scaling’ theory advocates that the inferred three-dimensional structure of the pictured object is used by the perceptual system to adjust the size of line-drawing components. Such a theory would predict that additional depth cues, for instance shading added to line drawings, should affect these illusions because they influence the three-dimensional appearance. We present here systematic measurements of the magnitude of length misjudgments in horizontal Müller-Lyer and Judd figures for three configurations: (i) pure line drawings, and with shading attached to (ii) the top, and (iii) the bottom of the figures. The latter two configurations are unambiguously interpreted as ‘folded’ structures with a horizontal edge behind the image plane or protruding from it, respectively. While we could not find any effect of shading in our experimental data, we did observe a length misjudgment in Judd figures that corresponds precisely to the asymmetry that can be observed in the Müller-Lyer illusion for inward and outward fins. This pattern of results is not consistent with notions of inappropriate constancy scaling but is fully coherent with the view that neural filtering mechanisms, which are affecting the perceived position of line intersections, are responsible for this type of geometrical illusions.

1 Introduction

Some of the best known and most surprising visual illusions can be elicited by very simple line drawings, in which the observer is hugely misled about the position, size, or orientation of certain components in simple geometrical figures (Robinson 1972). The Müller-Lyer illusion demonstrates substantial perceptual errors in estimating the length of—for instance horizontal—lines (‘shafts’) which have pairs of lines (‘fins’)

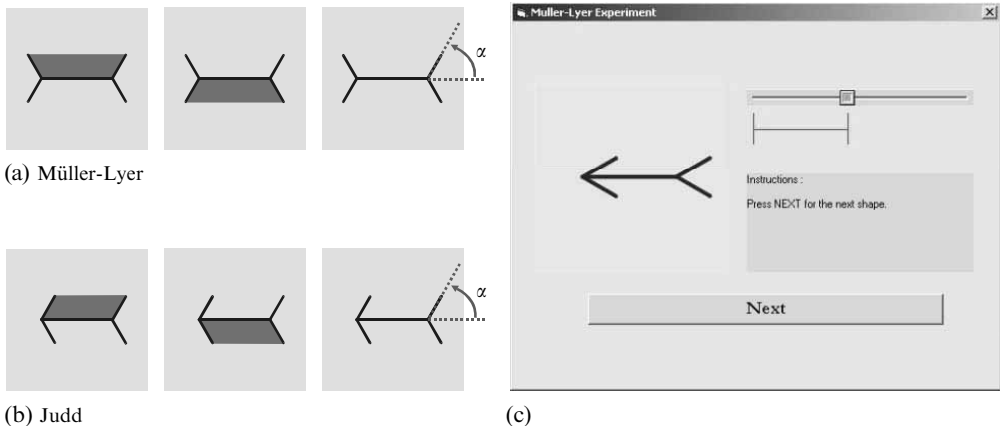


Figure 1. (a) Examples of Müller-Lyer stimuli and (b) Judd stimuli with shading attached to the top and the bottom of the figure, and without shading (from left to right); (c) experimental window as it appears on the computer screen with stimulus field on the left side and slide ruler on the right side to adjust perceived length (thin lines).

attached to their ends at oblique angles (see figure 1a for examples). This phenomenon is arguably one of the most prominent and stunning cases of visual illusions, attracting a lot of experimental studies since the early days of psychophysics (Judd 1905). Many hypotheses have been developed about the origin of such misjudgments, which often were used as a critical and integral part of more comprehensive theories of visual perception in general (Gregory 1997). Explanations for the Müller-Lyer illusion fall into two main categories, either (i) based on high-level perspective interpretations of the line drawings on one hand, or (ii) relating the illusions to low-level image processing mechanisms that may confuse the actual spatial relationships to be judged (see, for instance, DeLucia and Hochberg 1991).

The label 'perspective theory' refers to a group of high-level explanations that relate the line drawing to a three-dimensional (3-D) structure. In the Müller-Lyer figure, the perceptual system is believed to draw inferences about the depth of the shaft and to adjust perceived length to that consistent with the 3-D structure. The 'inappropriate constancy scaling theory' draws upon the fact that closer objects are actually smaller than their appearance in terms of retinal size, while more distant objects are actually larger than their appearance, and suggests as explanation of the Müller-Lyer illusion that in the 3-D interpretation the line that is perceived as more distant is re-scaled, thus to be perceived as the larger object (Gregory 1963). This view is supported by measurements of the depth perceived in luminous Müller-Lyer figures viewed monocularly (Gregory 1968; Jaeger 1975), but is challenged by a range of observations that the illusion can also be observed in physical 3-D structures generating the same kind of retinal images while providing reliable depth information (DeLucia and Hochberg 1991; Massaro and Anderson 1970; Nijhawan 1991) and stereoscopic stimuli (Georgeson and Blakemore 1973; Morrison 1977).

Low-level explanations of the illusion, on the other hand, emphasise the effects of filtering in the early visual system which can lead to confusions about the location of line endings (for review, see Coren and Girgus 1978). Optical blur, as most peripheral cause of image degradation in the visual system, has been demonstrated to affect the size of the Müller-Lyer illusion (Ward and Coren 1976). If the line drawing of the Müller-Lyer illusion figure is blurred in the neural representation of early visual system, blobs appear at the joints between shaft and fins in the 'low-passed' version of the stimulus. The distance between the centres of the two blobs depends on the fin angles—it would be smaller for the configuration with inward-directed fins and larger for the configuration with outward-directed fins. The blur hypothesis about the Müller-Lyer illusion assumes that perceptual length estimates are based on the distance between the peaks of neuronal activation, corresponding to the centres of neural blur, thus leading to the observed variation in perceived length (Coren and Girgus 1978). This view is supported by observations that the illusion depends on a misjudgment of the shaft endings rather than a homogenous compression or expansion of the shaft (Morgan et al 1990; Post et al 1998) and by computer simulations of geometrical illusions in basic line drawings (Morgan and Casco 1990) which can link length and orientation misjudgments in the Zöllner–Judd class of geometrical illusions (see, on the other hand, Earle and Maskell 1995). However, it has been argued against this view that line drawings are not perceived as blurred and the size of length misjudgments would be going beyond that expected for simple image blurring (Gregory 1998), and that the illusion is not affected by blurring the stimulus (Stuart and Day 1980). Furthermore, observers are much better in judging the location of the line endings—which should be affected by blurring in the same way as estimating the length—than would be expected from the size of the length illusion (Gillam and Chambers 1985).

The dispute about the origins of the Müller-Lyer illusion seems not to be fully settled, so we present here data from a simple computer experiment under conditions

not tested so far, which manipulate the 3-D interpretation of the line drawings. If, in a horizontal orientation of the Müller-Lyer figures, grey shading is added, inward (valley fold, shadow attached to the top of the figure) and outward (mountain fold, shadow attached to the bottom of the figure) configurations of a 3-D structure can be inferred from the fact that such shading would be generated by lighting from above. From inappropriate size constancy scaling it could be predicted that added shading should enhance or reduce the length misjudgment for the inward and outward configuration, respectively, as compared to the neutral configuration without shading.

Looking at the symmetry properties of the Müller-Lyer figure, a second, complementary, configuration can be constructed in which the fins on each side of the shaft are parallel rather than oriented in opposite directions, leading to arrowheads pointing in the same direction (see figure 1b). This type of line drawing was originally studied by Judd (1899)—and the misperception of the midpoint (eg Morgan 1969) and the overall position (eg Holding 1970) of the shaft in this figure is now generally referred to as the ‘Judd illusion’ (Gillam and Chambers 1985). These illusions attracted some recent attention in the discussion about separate pathways for perception and action (Mon-Williams and Bull 2000) and were consequently tested with neglect patients (Olk et al 2001). In the present context it is important to note that the Judd figure could invite even clearer 3-D interpretations than the Müller-Lyer figure, being perceived as similar to a partially opened book (sometimes referred to as Mach’s reversible open-book illusion). By adding shading, the perceived depth percept should be biased towards an inward (shading attached to the top of the figure) or outward (shading attached to the bottom of the figure) pointing configuration, which again should affect the perceived length of the shaft, assuming mechanisms of constancy scaling. Therefore in a second experiment we collected data for Judd figures with top and bottom shading and for controls without shading. We will demonstrate that an interesting asymmetry between the inward and outward fins that previously has gone largely unnoticed for the Müller-Lyer figure, leads to some misjudgment of length in Judd figures that to our knowledge has not been reported so far.

2 Materials and methods

Experiments were carried out in a quiet room with low ambient illumination. A proprietary experimental program (written in Visual Basic, running under the Windows 2000 operating system) was used to control stimulus presentation and collect the observers’ responses. Participants were seated comfortably in front of the PC monitor, at normal reading distance (~ 50 cm), and were instructed by the experimenter how to control the application which generated a control window in the centre of the screen (an exemplary screenshot is shown in figure 1c).

Each stimulus was presented in a light-grey rectangular field (8 cm \times 8 cm) on the left side of the application window. The participants were asked to use the mouse to set the slide rule on the right side of the application window such that the length of the thin red horizontal line below the slide rule fitted the perceived length of the shaft of the stimulus figure. Participants were allowed as much time for each setting as they wanted, pressing the ‘next’ button in the application window when they were satisfied with their setting, to continue with the next trial (see figure 1c). The stimulus type and configuration, together with the setting of perceived length (in relative units) were saved for each trial on disk for further analysis.

Each stimulus set consisted of line drawings with five different fin angles, α (30° , 60° , 90° , 120° , 150° ; for definition of α , see sketches in figure 1), and for each of three configurations with top, bottom, and without shading (see figures 1a and 1b). The shaft lines (shaft length 40 mm, corresponding to 4.6 deg at a viewing distance of 50 cm, fin length 15 mm, line thickness 3 mm) were always oriented horizontally.

Each of these 15 stimuli was presented 5 times, in random order, to provide 5 measurements for each stimulus from every participant. For the two experiments we used two different stimulus types, namely Müller-Lyer (figure 1a) and Judd (figure 1b) figures. Participants carried out the two experiments in counterbalanced order.

Twenty volunteers (thirteen female, seven male) from the Royal Holloway University student population were recruited for these experiments. They were normally sighted or were wearing their usual optical corrections. The experiments conformed to the College ethical procedures.

3 Results

The results from the first experiment, with the Müller-Lyer figure, are shown in figure 2. The averages of perceived length are plotted as a function of fin angle for the three shading conditions. First, it should be noted that there is a bias on the complete data set—even for the figures with vertical fins (90° , looking like a stretched ‘H’) the observers did not adjust the slide ruler to the veridical length but underestimated it by 3–4 mm. This misjudgment could be due to the spatial layout of the stimulus-response window, or could be caused by differences in line colour or thickness between the stimulus figures and the test line that the observer has to adjust to match stimulus length, but is not critical in the present context because we focus on the differences between this neutral stimulus ($\alpha = 90^\circ$) and those with larger (inward fins) or smaller (outward fins) fin angles. It is clear from such a comparison that there is a very strong and contiguous dependence of perceived length on fin angle, in that the perceived length increases by up to 8 mm for the outward fins and decreases by ~ 4 mm for the inward fins. This asymmetry between inward and outward fins can be seen in published data (Gregory 1968) but has not attracted a lot of attention so far. It will be important for interpreting length misjudgments for Judd stimuli (our second experiment). Finally, and perhaps most strikingly, the curves for stimuli without shading,

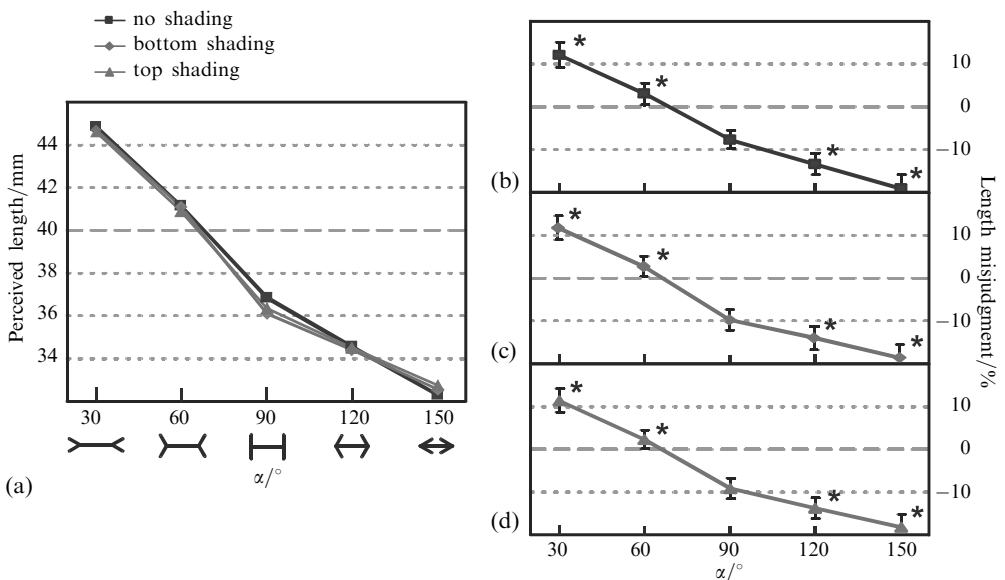


Figure 2. Length judgments for Müller-Lyer stimuli (see sketches below abscissa). (a) Perceived length as function of fin angle, α , for control stimuli without shading, shading attached to the bottom of the figure, and to the top of the figure (indicated by different symbols); length misjudgments in percentage of veridical length for (b) control stimuli, (c) bottom-shading figures, and (d) top shading figures (averages from twenty participants, with SEMs plotted as error bars; significant differences from control condition— 90° —are marked by an asterisk).

and with shading attached to the top or bottom of the figure, respectively, lie almost perfectly on top of each other, giving a very strong indication that there is no effect of adding shading cues to manipulate the 3-D appearance.

These results are re-plotted in figures 2b–2d as percentage of length misjudgments separately for the three shading conditions, to illustrate the dimension-free size and significance of the observed effects. The overall range of misjudgment is substantial, about 30% of the shaft length, with error bars of about $\pm 3\%$, and does not depend on the shading condition. The maximum difference for outward fins (30° versus 90°) is about 20%, whereas the maximum difference for inward fins (150° versus 90°) is about 10%. Statistical analysis with a repeated-measures ANOVA reveals highly significant differences for the stimulus variable ‘fin angle’ ($F_{4,76} = 58.99$, $p < 0.001$), no effect of the stimulus variable ‘shading condition’ ($F_{2,38} = 0.355$, $p > 0.05$), and no interaction between fin angle and shading condition ($F_{8,152} = 0.479$, $p > 0.05$). A posteriori analysis confirmed that differences between average misjudgments for all pairs of fin angles are significant within each shading condition (paired two-tailed t -tests, $p < 0.05$).

The results from the second experiment, with the Judd figure, are shown in figure 3. The averages of perceived length are plotted as function of fin angle for the three shading conditions (indicated by different symbols in figure 3a). Once again, we observe the same bias on the complete data set as in the first experiment (cf figure 2a)—for the figures with vertical fins (90°) the observers underestimated the shaft length by almost 4 mm on average. Looking at the differences between this neutral stimulus and those with larger or smaller fin angles, it is clear that there is a length illusion in these line drawings—depending on α , the shaft is perceived as up to 2–3 mm longer than in the neutral configuration with vertical lines at both ends of the shafts. This length misjudgment corresponds to approximately half the asymmetry between illusion magnitude for inward and outward fins in the Müller-Lyer figures (cf figure 2a). It suggests that the combination of an inward-directed set of fins and

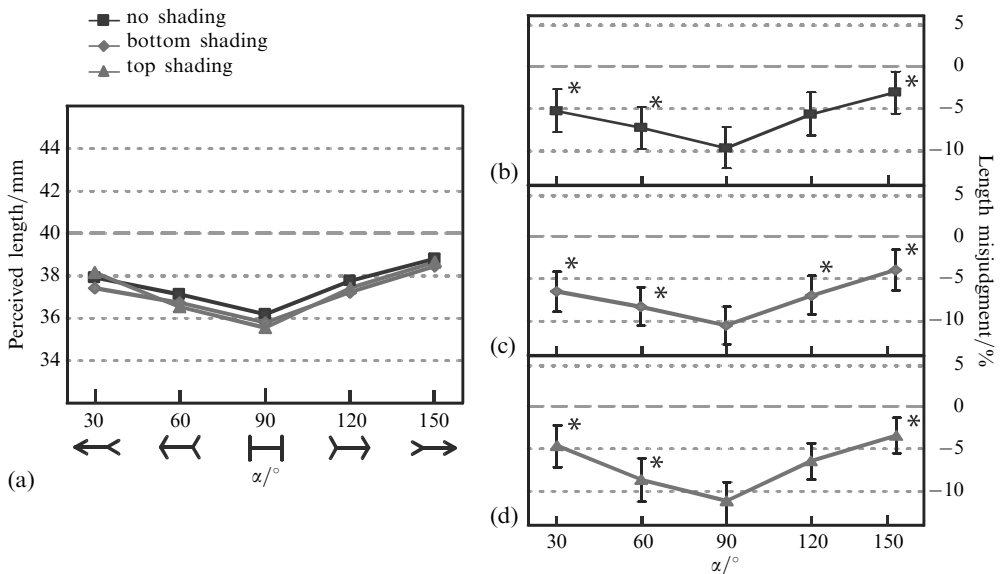


Figure 3. Length judgments for Judd stimuli (see sketches below abscissa). (a) Perceived length as function of fin angle, α , for control stimuli without shading, shading attached to the bottom of the figure, and to the top of the figure; length misjudgments in percentage of vertical length for (b) control stimuli, (c) bottom shading figures, and (d) top shading figures (averages from twenty participants, with SEMs plotted as error bars; significant differences from control condition— 90° —are marked by an asterisk).

the outward-directed set of fins used in the Judd figure drives the length illusion in the same manner in which it is driven by mirror-symmetrical fin arrangements in the Müller-Lyer illusion of the first experiment. Finally, perfectly consistent with the results of the first experiment, the curves for all three shading conditions superimpose again, confirming the conclusion from that experiment that there is no effect of manipulating the 3-D appearance by adding shading cues.

These results are re-plotted in figures 3b–3d as percentage of length misjudgments separately for the three shading conditions, to illustrate the dimension-free size and significance of the observed effects. The overall range of misjudgment is in the range of 5%–8% of the shaft length, with error bars of less than $\pm 3\%$, and does not depend on the shading condition. Statistical analysis with a repeated-measures ANOVA reveals highly significant differences for the stimulus variable ‘fin angle’ ($F_{4,76} = 21.80$, $p < 0.001$), no effect of the stimulus variable ‘shading condition’ ($F_{2,38} = 1.32$, $p > 0.05$), and no interaction between fin angle and shading condition ($F_{8,152} = 0.81$, $p > 0.05$). A posteriori analysis confirmed that differences between average misjudgments for 10 out of 12 pairs of fin angles are significant within the shading conditions (paired two-tailed *t*-tests, $p < 0.05$, marked with asterisks in figures 3b–3d).

4 Discussion

In order to test the validity of perspective theories of illusions, we measured the magnitude of length misjudgments in simple line drawings in the presence and absence of shading, which affects the 3-D interpretation of the drawing. The quantitative data resulting from the experiments presented here give rise to two main conclusions.

(i) Contrary to the expectations based on perspective theories of perception, and despite the fact that we observed substantial changes in illusion strength in relation to other stimulus parameters, we could not find any effect of shading in both stimulus configurations (Müller-Lyer and Judd) and under any of the conditions employed here. Because we did not measure perceived depth directly (unlike Gregory 1968), we cannot say exactly how misperceived length is related to perceived distance in our experiments. However, it is clear from introspection that shading disambiguates the depth interpretation of the line drawings used, in particular in the case of the Judd patterns, while it has no effect on perceived length. An interesting question for the future will be to follow up this issue, for instance by studying for Judd figures what distance and size effects can be observed in reaching and grasping. The complete absence of any shading effect in our experiments suggests that the 3-D interpretation of the line drawing is not crucial for the measured length illusion, and therefore is at odds with the inappropriate constancy scaling theory (Gregory 1963), while it lends further support to alternative views that have been derived from experiments with stereoscopic and physical 3-D versions of the illusory stimuli (DeLucia and Hochberg 1991; Georgeson and Blakemore 1973; Massaro and Anderson 1970; Nijhawan 1991). On the basis of these results, one would favour explanations of the illusion in terms of misperceived locations of the line endings due to the obliquely intersecting fin lines.

(ii) We find a small, but highly significant, length misjudgment in Judd figures, which depends on the angle between the shaft and the fin lines. This effect, to our knowledge, has not been measured before, and could be thought of as supporting perspective theories, because the Judd figure invites a strong (but ambiguous) 3-D interpretation that lifts the horizontal line out of the image plane. However, the failure to bias this length illusion into one or the other direction by attaching shading which should favour convex or concave interpretations casts serious doubts over such an explanation. In the framework of misjudging the locations of line endings, the length illusion in Judd figures indeed is rather unexpected initially because one would assume that the outward-directed and inward-directed fins in this figure should compensate for

each other. However, a closer look at the data for the Müller-Lyer illusion reveals that outward-directed fins have a larger effect on perceived length than inward-directed fins, which would both qualitatively and quantitatively account for the misjudgment of shaft length in the Judd figure by assuming systematic errors in the perceived location of the two shaft ends. Corresponding mechanisms (ie re-scaling space along the shaft) have been discussed as the cause of the perceptual shift midpoint location in Judd figures, and similar asymmetries can be seen in the data sets for judging locations on shafts of both Müller-Lyer and Judd figures (Morgan et al 1990; Post et al 1998). Furthermore, this interpretation that the effects of fin pairs on shifting perceived location are superimposed for different figure designs is consistent with the observation that configurations with partial fin amputations lead to partial misjudgments (Predebon 1996), which once again is in conflict with perspective theories.

In conclusion, we could not find any effect of shading that might be interpreted in favour of perspective effects, but did observe a curious length misjudgment in Judd figures that corresponds to the asymmetry of the Müller-Lyer illusion for inward-directed and outward-directed fins. This pattern of results is not consistent with notions of inappropriate constancy scaling, but is fully coherent with the view that some neural filtering mechanism that is affecting the perceived position of line intersections is responsible for this type of geometrical illusions.

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