

Titchener's \perp dissected

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Abstract In three experiments, two independent samples of 12 observers each visually inspected modified versions of Titchener's \perp from which the T-junctions had been deleted. For Experiment 1, the \perp 's two lines had been replaced by dashed lines not meeting in a common point; for Experiment 2, the \perp had been reduced to five dots, representing the original lines' end- and midpoints; and for Experiment 3 (in which the second sample of observers served), the \perp had been dissected into two separate lines, differently spaced from each other. Observers haptically indicated the lengths of the two orthogonal lines of the modified \perp s and verbally judged their relative lengths or the distances between the corresponding dots. The common perceptual illusions persisted in Experiments 1 and 2, but were markedly weakened in Experiment 3. Implications for a neurophysiological account of the illusions in terms of bottom-up, long-range interactions between orientation-sensitive mechanisms versus top-down activation of a figural schema are spelled out.

Keywords Visual illusion · Haptic signaling · T-junctions · Figural completion · Retinal eccentricity

As has apparently been known for centuries (Pastore, 1971), the Latin letter T gives rise to a strong and stable visual illusion: If both of its constitutive lines are equally long, the upstroke appears to be longer than the cross-stroke. In psychology, the illusion is known as *Titchener's \perp* , since Titchener (1901) introduced an inverted T as an illustration of the so-called *horizontal-vertical illusion*, which typically consists in

a relative overestimation of vertical extents relative to horizontal ones—as has often been demonstrated with an L figure (e.g., Avery & Day, 1969; but see Chapanis & Mankin, 1967, for exceptions). Finger and Spelt (1947) were among the first to note that Titchener's \perp incorporates at least two illusion-inducing factors: the orientation of the lines and the bisection of the horizontal line by the vertical one. Later, Künnapas (1955), by gradually transforming the \perp into an L and by presenting the figures in upright and lateral orientations, attempted to quantify the contributions of these two factors, and found bisection to be the stronger one. However, Verrillo and Irvin (1979), using the method of absolute magnitude estimation, had observers judge the lengths of individual, luminous lines in complete darkness and found no differences for horizontal versus vertical lines. They therefore concluded that “when care is taken to eliminate [contextual] cues . . . , the Horizontal–Vertical Illusion does not exist” (p. 270).

In several experiments (Landwehr, 2009, 2014, 2015a, 2015b), I have shown that the \perp illusion, albeit in a weaker form, also occurs in the haptic domain when observers visually inspect the stimulus and then haptically signal line lengths by spreading the thumb and index finger appropriately (cf. Gibson, 1966). Attempts to influence the illusion(s), by rotating the \perp into lateral or oblique positions (Hamburger & Hansen, 2010; Künnapas, 1955; Landwehr, 2009, 2014) or putting it into different contexts (Landwehr, 2015a), met with limited success. The illusions even persisted in triangles and catenary-derived forms (Landwehr, 2015a, Exp. 3), suggesting that the T-junction as such does not even have to be optically specified for the illusions to occur. The present series of experiments continued with this idea and tested modified \perp s with deleted or only implicitly specified T-junctions. The embarrassing insight was that there does not appear to be any possibility to completely destroy the visual \perp illusion (the haptic illusion did vanish with branching patterns;

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Landwehr, 2015a, Exp. 2). Implications for a neurophysiological account in terms of interactions between orientation-sensitive mechanisms (Caelli, 1977) versus response determination by figural schemas (Wertheimer, 1922, 1923) will be considered in the [General Discussion](#).

General method

Participants

Two independent samples of 12 observers each, one sample taking part in Experiments 1 and 2 and the other in Experiment 3, were recruited from the psychology undergraduate population at the University of Mainz. Informed consent was obtained from all observers, and persons were treated according to the WMA Declaration of Helsinki (World Medical Association, 1964/2013). Participants served in partial fulfillment of a class requirement. All participants had normal or corrected-to-normal vision, and all but two were right-handed. The left-handers experienced no difficulties with the haptic task, nor did their data deviate from those of the others.

Apparatus, target specification, and response measures

The essential part of the apparatus was a touch-sensitive computer screen (size: 50.9×28.6 cm; resolution: 1,920×1,080 pixels; response time: 5 ms) that was used for both stimulus presentation and response registration. For Experiment 3, the screen was oriented frontoparallel at a distance of 44 cm from the observer; for Experiments 1 and 2, an additional, horizontal orientation of the screen was arranged by setting it flush into a table. Stimuli were presented within a circular, light gray window (diameter: 28.5 cm; plane visual angle: 35.9×35.9 deg or 35.9×31.3 deg; luminance: 228 cd m⁻²; dominant wavelength: $\lambda=478$ nm; CIE coordinates: $x=0.306$, $y=0.308$; Weber contrast between stimulus and background: $C_W=-0.998$); the rest of the screen was dark (0.355 cd m⁻²), and there was only faint, indirect illumination of the room.

For haptic trials, the stimulus presentation time was 2.4 s, and the interstimulus interval, during which participants had to deliver their response, was 3 s. Haptic trials were experimenter-paced in order to avoid speed–accuracy trade-offs. Participants were instructed to respond immediately after stimulus wipe-out and then to rest their active hand on a marked resting position to the right or left of the stimulus presentation window. For visual trials, a participant's response started the next trial after a delay of 200 ms. The visual trials were participant-paced so that quick responses would not entail unduly long waiting periods until the next trial. The target elements of the stimuli (lines or dots) were specified by changing their color from black to red for 200 ms, and then back to

black for another 200 ms, during the last 400 ms of their presentation time. Subjectively, this change appeared as blinking.

During haptic trials, participants had to indicate a target distance by spreading the thumb and index finger and leaving a virtual trace on the computer screen. Prior to the experiments, the response was exercised by having participants grasp a thin wooden bar at its ends with a pincer grip. It was demonstrated that the interdigit distance varied with the force of the grip, due to skin indentations, and that the distance immediately before the actual grasp was the relevant measure. Participants also practiced touching the computer screen to guarantee reliable signal transmission (for details about how a mean interdigit distance estimate was derived from participants' raw responses, see Landwehr, 2014, p. 1154). On visual trials, participants had to gently push one of three gray buttons marked on the computer screen, labeled *longer*, *equally long*, and *shorter*, respectively. Successful registration of responses was confirmed by the buttons briefly shining light blue.

Experiment 1

Experiment 1 was an exact replication of one of my earlier experiments (Landwehr, 2014), except that the full-line \perp stimulus was replaced by a dashed-line stimulus (Fig. 1a). Stimuli were shown in a frontoparallel or in a horizontal orientation, and they were rotated full-circle around the midpoints of target distances in steps of 45 deg. As in my earlier experiments (Landwehr, 2009, 2014), in order to avoid awkward elbow and wrist flexions, four angular rotations each were linked to the definition of the target distance: For angles of 0, 135, 180, and 315 deg, the target was the \perp 's upstroke; for angles of 45, 90, 225, and 270 deg, its cross-stroke (rotation angles were based on the cross-stroke; at 0 deg, this stroke, lying at the bottom of the \perp , was horizontal, and rotation was counterclockwise). As will be evident from the results, the partial confounding of rotation and target line did not have detrimental consequences with regard to the interpretability of the effects; however, as will be explained and justified later, the confounding was eventually removed for the visual trials of Experiment 3 as well as for more recent experiments (Landwehr, 2015b, Exps. 2 and 3). Stimuli were scaled in size by factorially crossing three different lengths of their constituent parts (6.5, 7, and 7.5 cm, corresponding to 7.12~8.45, 7.67~9.1, and 8.22~9.74 deg of visual angle, respectively, depending on screen orientation).

Method

Stimuli, hypotheses, and design For the construction of differently long dashed lines, either the lengths of the segments or the sizes of the gaps can be held constant—or both can be

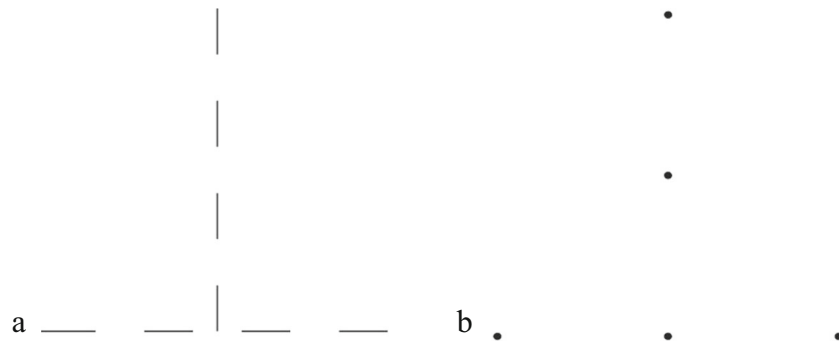


Fig. 1 (a) Titchener's \perp , with its original lines being replaced by dashed lines (Exp. 1). (b) Titchener's \perp reduced to five dots, representing the original lines' end- and midpoints (Exp. 2)

varied concomitantly. After inspecting test stimuli, I decided on the last option, because the other ones yielded impressions of shrinking or stretching of the whole \perp -figure across trials when the lengths were varied. There were four segments and three gaps within each line. One endpoint of the \perp 's upstroke fell in the middle of the central gap of the \perp 's cross-stroke (see Fig. 1a). Both parts of the stimulus were thus clearly specified with regard to their outermost ends, but no T-junction was expressly drawn. Given that such an optically specified junction had proven unnecessary for the effects in question to occur (see the introduction), I predicted that both the haptic and visual \perp illusions would be unaffected. Although screen orientation had shown only a minor effect in my corresponding previous study (Landwehr, 2014), that variable was kept because with dashed lines (and also with dots; see Exp. 2), perspective gradients might be more conspicuous than with full lines (Gibson, 1950). Variations of stimulus size and rotation made for $9 \times 8 = 72$ trials, which were ordered randomly. During two sessions, spaced one or two weeks apart, participants did 72 haptic plus 72 visual trials with one orientation of the computer screen (horizontal or frontoparallel), and then the same number of trials with the other orientation of the screen, with the sequence of screen orientations balanced across observers. At the end of each session, participants also performed Experiment 2, which comprised another 72 visual trials per screen orientation.

Results and discussion

Concerning the haptic data, the orientation of the computer screen—frontoparallel versus horizontal—did not exert any significant effects; therefore, these data were aggregated. Linear regressions of the haptically indicated line lengths to the differences of presented lengths from the mean length of 7 cm yielded the following equations: for the \perp 's upstroke, $y = 0.809 \delta_x + 7.442$, $R^2 = .161$; for the cross-stroke, $y = 0.786 \delta_x + 7.035$, $R^2 = .159$. The net percent amount of the illusion, calculated from the difference of the intercepts

in order to remove effects of the general overshooting of lengths, was 5.81 %, and thus even greater than for the full-line \perp (Landwehr, 2014; in that experiment, the divided line and also the undivided one were often undershot in the oblique rotation). Possibly, an illusion of numerosity, due to the dashed lines' composition of several elements, intervened (Ponzo, 1928). A Greenhouse–Geisser-corrected, repeated measures analysis of variance (rmANOVA) revealed main effects of length and type of target line, $F(1.574, 17.317)_{UP} = 79.301$, $p < .001$, $\eta_p^2 = .878$, $F(1.741, 19.151)_{CROSS} = 111.126$, $p < .001$, $\eta_p^2 = .910$; $F(1, 11) = 69.853$, $p < .001$, $\eta_p^2 = .864$, and of rotation, $F(1.361, 14.967) = 8.472$, $p < .007$, $\eta_p^2 = .435$, as well as an interaction effect between type of target line and rotation, $F(2.429, 26.714) = 3.807$, $p < .028$, $\eta_p^2 = .257$, which is illustrated in Fig. 2, in the lower sequence of data points. No other main or interaction effects emerged. These results confirmed that observers, although being quite proficient in discriminating line lengths, fell prey to the haptic \perp illusion with dashed-line \perp s. Simple contrasts showed that only the \perp 's upstroke in a vertical orientation (0 and 180 deg) was indicated to be reliably longer than the \perp 's cross-stroke (90, 270, and 225 deg); at oblique orientations (135 and 315 deg), the upstroke was indicated to be longer only when the cross-stroke was also obliquely oriented (45 and 225 deg). Hence, despite their having been partially confounded, separately identifiable effects of both rotation and target line were apparent. This agrees with earlier findings that I had interpreted as demonstrating the contribution of an—inherently contextual—horizontal–vertical effect to the \perp illusion (Landwehr, 2009, 2014).

Visual data, as before (Landwehr, 2009, 2014, 2015a, 2015b), were analyzed by fitting psychometric functions. Function parameters were derived from the binary logistic regression routine of SPSS, and points of subjective equality (PSEs) were obtained from the cross-points of the functions for *longer* and *shorter* judgments, plotted against an abscissa defined by the difference in length of the two parts of the dashed \perp -figure (cross-stroke minus upstroke; cf. Urban, 1908). For the two orientations of the computer screen—

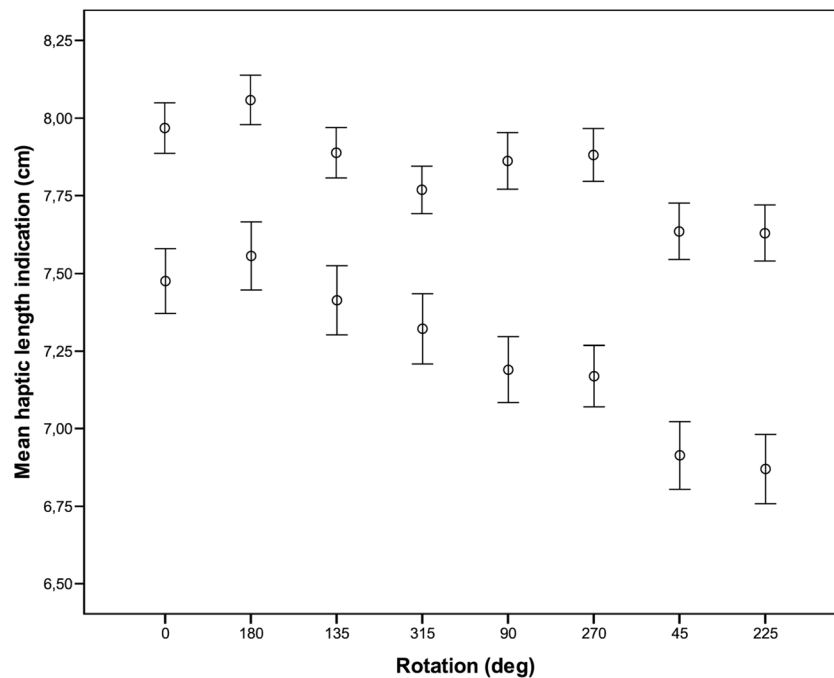


Fig. 2 Mean haptic length indications for the stimuli shown in Figs. 1a (lower sequence of data points) and 3 (upper sequence of data points). Rotation angles of 0 and 180 deg refer to the figure's original upstroke at a vertical orientation; 135 and 315 deg to this stroke at an oblique

orientation; and 90, 270, 45, and 225 deg to the original cross-stroke at pairwise corresponding orientations. Bars indicate 95 % confidence intervals

frontoparallel versus horizontal—the visual \perp illusion was found to be a 12.09 % or 11.40 % overestimation of the upstroke. Apparently, the effect of screen orientation was small—as were the effects of the direction of comparison (i.e., whether the undivided line had to be compared to the divided one, or vice versa). Although the amounts of illusion were roughly comparable to those found in the corresponding earlier experiment (Landwehr, 2014), they rendered any possible effects of perspective ambiguous, because in that earlier experiment, the \perp illusion had been markedly greater for the horizontal orientation of the stimulus presentation screen (Landwehr, 2014, p. 1156). Taken together, the results from both the haptic and visual trials supported my hypothesis that a dashed-line \perp , in which the T-junction is only implicitly specified, can be substituted for a full-line \perp without substantially altering the typical illusion effects.

Experiment 2

As is shown in Fig. 1b, a convincing, minimum illustration of a \perp can be achieved with five dots. Would the haptic and the visual \perp illusions still survive with this sparse, implicit specification of a T-junction? The apparatus and stimulus parameters were kept from Experiment 1. Experiment 2 was run as a purely visual experiment because previous experiments, in which target distances had been specified by blinking dots, had already shown that haptic performance

was close to perfect under this condition (Landwehr, 2015a, Exp. 3 and the practice trials preceding that experiment). Hence, for two orientations of the stimulus presentation screen, only 2×72 trials were left. Because the stimuli of Experiments 1 and 2 appeared sufficiently different, data were solicited from the same sample who had served for Experiment 1.

Results and discussion

The data were analyzed as in Experiment 1. For the two orientations of the computer screen (frontoparallel vs. horizontal), the visual \perp illusion amounted, respectively, to a 9.68 % or a 11.20 % overestimation of the “upstroke” of the dotted \perp figure. However, in this experiment, with a horizontal orientation of the stimulus presentation screen, the illusion was markedly greater when the \perp 's upstroke had to be compared to the \perp 's cross-stroke (13.18 %), rather than vice versa (9.22 %), partly reestablishing a (still unexplained) effect seen in my earlier study (Landwehr, 2014). Presumably, participants treated the dot sequences as being equivalent when seeing them in a parallel perspective, and as nonequivalent in polar perspective—when either one or both of the sequences were subject to (different amounts of) perspective and foreshortening. Irrespective of this specific effect, the visual \perp illusion clearly persisted with the nonlinear, dotted \perp s at both orientations of the computer screen.

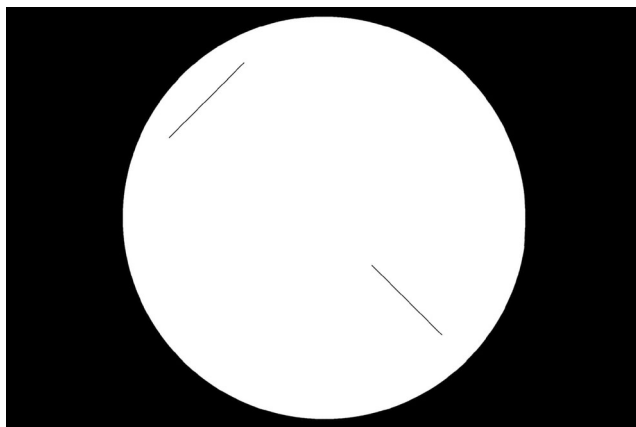


Fig. 3 Screenshot of an example stimulus from Experiment 3, with Titchener's \perp dissected into two separate lines (rotation angle: 225 deg; gap size: 16 cm)

Experiment 3

Although the stimuli used in Experiments 1 and 2 did not contain an explicit T-junction, it was still the case that one endpoint of the \perp -figure's upstroke coincided with the midpoint of the \perp -figure's cross-stroke. Hence, the integrity of the \perp was still preserved. For Experiment 3, Titchener's \perp was "dissected"—that is, torn apart into two separate lines (Fig. 3). In a prestudy, I had found gaps of up to 8 mm (1 deg of visual angle) to be noneffective; therefore, much larger gaps were used. On the basis of knowledge about "zones" of the retina (i.e., areas that differ with regard to differential photoreceptor densities as well as cortical magnification; Gilbert, 2013; Polyak, 1941; Wässle & Boycott, 1991), gaps were selected so as to exceed the diameter of the fovea (3 cm \equiv 3.9 deg of visual angle) or the macula (10 cm \equiv 13 deg of visual angle), or else to be large enough to shift both lines to the far periphery—so that only one line at a time could be foveated. The size of the largest gap (16 cm \equiv 20.6 deg) was limited by the size of the presentation window (cf. the General Method). In a second prestudy, an instruction to fixate the center of the computer screen proved to be unworkable with naïve participants. Because a fixation mark might have affected performance, I did not try to constrain eye movements. In fact, my coworkers and I observed that without eye movements, the specification of the target, when it was located in the retinal periphery, was often missed. Most probably, this has to do with the absence of a sufficient number of cone photoreceptors in the retinal periphery (Lee, Martin, & Grünert, 2010). For visual trials, the partial confounding of target line and rotation had to be removed because test observers soon developed expectations about which line would be the target, and they immediately saccaded toward that place on the screen, so that the target was always extensively foveated—a new and critical confound that had to be avoided. We removed this confound by having observers compare every line with every other one. Why the

original confound was less easily detected during haptic trials is not clear. However, in a postexperimental inquiry, two participants remarked that they had noticed it.

Method

Design and hypotheses The basic variations of the previous experiments were kept. However, in order to eliminate possible effects of perspective, which were no longer of interest for this experiment, the focus of which was on retinal image gaps, only the frontoparallel orientation of the computer screen was used. Together with three gap sizes, this now required $72 \times 3 = 216$ haptic trials. The visual condition included twice this number of trials, because now every line had to be compared with every other one. The 432 visual trials were secured during two separate sessions. With reference to my suggestion that the \perp illusions can probably be explained in terms of (mainly local) interactions between orientation-sensitive neural mechanisms (Landwehr, 2009, 2014), I expected the illusions to decrease in proportion to gap size.

Results and discussion

For the haptic data, linear regressions were computed analogously to Experiment 1, yielding the following equations: for the \perp 's upstroke, $y = 0.660 \delta_x + 7.921$, $R^2 = .134$; for the cross-stroke, $y = 0.713 \delta_x + 7.752$, $R^2 = .125$. Thus, the net percent amount of the illusion was 2.41 %, which is quite in the range of what had been seen with individual, nondissected \perp s (Landwehr, 2009, 2014), as well as with \perp s arranged in discrete, cyclically symmetric 4- \perp patterns (Landwehr, 2015a). When computed separately for the three gap sizes, the illusion amounts were 3.71 %, 1.43 %, and 2.00 %, for 3, 10, and 16 cm, respectively. An rmANOVA revealed main effects of length and type of target line, $F(1.661, 18.268)_{Up} = 123.809$, $p < .001$, $\eta_p^2 = .918$, $F(1.739, 19.134)_{Cross} = 42.370$, $p < .001$, $\eta_p^2 = .794$; $F(1, 11) = 8.520$, $p < .014$, $\eta_p^2 = .436$, rotation, $F(1.932, 21.257) = 9.736$, $p < .001$, $\eta_p^2 = .470$, and gap size, $F(1.457, 16.030) = 14.548$, $p < .001$, $\eta_p^2 = .569$, as well as an interaction effect between type of target line and gap size, $F(1.692, 18.613) = 5.261$, $p < .019$, $\eta_p^2 = .324$.

The effect of target line length means that participants again could clearly discriminate length increments of 0.5 cm (equivalent to 39 arcmin of visual angle). The effect of target line type, on the other hand, means that observers nonetheless fell prey to the \perp illusion, indicating that the original upstroke—which still targeted the other stroke's midpoint—was longer than the original cross-stroke. The effect of rotation (Fig. 2, upper sequence of data points) was similar to the one found in Experiment 1. This time, simple contrasts showed that only the \perp 's upstroke at a vertical orientation (0 or 180 deg) was indicated to be reliably

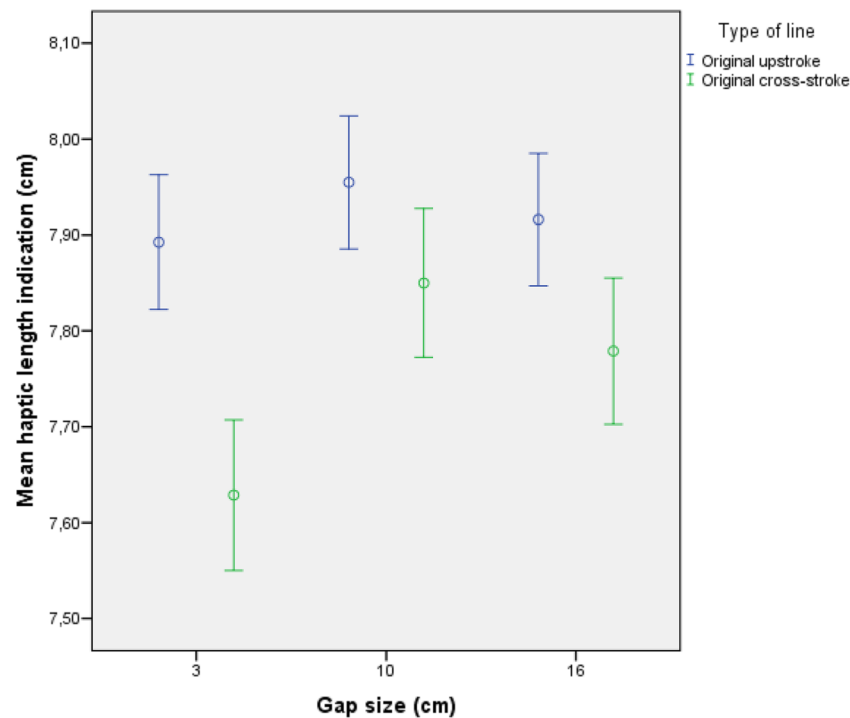


Fig. 4 Mean haptic length indications for the stimulus shown in Fig. 3, plotted separately for the two types of lines against the size of the gap between them

longer than the \perp 's cross-stroke at an oblique orientation (45 or 225 deg). The remnants of the haptic \perp illusion with dissected \perp s thus appear as a mix of effects of type of target line and rotation (remember that these two factors were still partially confounded in the haptic part of the present experiment). The gap size effect, as such, and the interaction effect between type of target line and gap size are illustrated in Fig. 4. Repeated contrasts confirmed that both adjacent gap size differences were significant with considerable effect sizes: 3 vs. 10 cm, $F(1, 11)=22.114$, $p<.001$, $\eta_p^2=.668$; 10 vs. 16 cm, $F(1, 11)=11.029$, $p<.007$, $\eta_p^2=.501$. It seems obvious, though, that effects were mainly due to the different undershootings of the cross-stroke's length.

The visual data were analyzed as in the preceding experiments. Computed across all gap sizes and all rotations, the original upstroke of the \perp was overestimated by 3.49 %. This number suggests that the visual illusion was much attenuated with a dissected \perp (cf. Exps. 1 and 2). When analyzed separately for the three gap sizes, the illusion amounts were 5.76 % at gap size 3 cm, 2.26 % at gap size 10 cm, and 3.30 % at gap size 16 cm (Fig. 5). So far, dissecting Titchener's \perp proved to be an effective means to reduce the visual illusion that is typically tied to this figure. However, reinspecting the visual raw data (i.e., the distributions of *longer*, *shorter*, and *same* responses) in the present experiment revealed that for angular rotations of 0 and 180 deg, there were more *longer* responses than for any other rotation. Fitting psychometric functions only for the upright variants of

the \perp (0 and 180 deg rotation) yielded an illusion of 12.69 %—that is, an overestimation of the original upstroke to a degree that is commonly seen with an undissected \perp ! Due to poor model fits, the amounts of illusion could not be estimated separately for all three gap sizes, to see whether the visual illusion behaved analogously in this subset of data and in the haptic data. However, for gap size 10 cm (for which the analysis worked), the illusion amounted to 9.65 %,

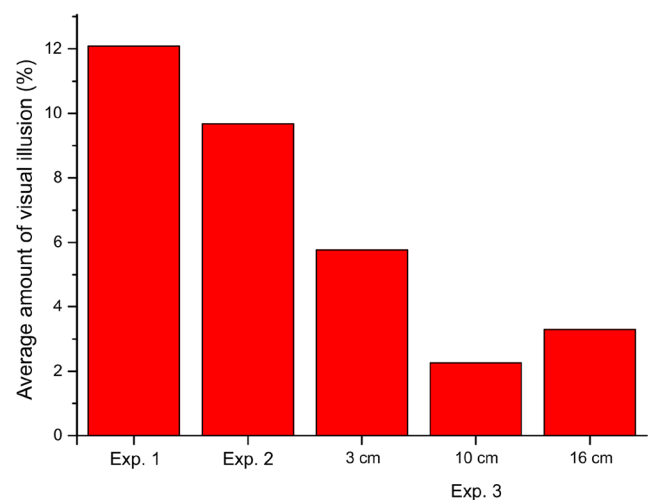


Fig. 5 Average percent amounts of visual illusion in the three experiments. For Experiments 1 and 2, values refer to the frontoparallel orientation of the stimulus presentation screen. For Experiment 3, the three bars refer to the three gap sizes used in that experiment

suggesting a slight decline. Although data plots (not shown) suggested that the illusion got larger at the largest gap size, binomial and chi-square tests of the frequency distributions of the corresponding response categories revealed no significant differences between gap sizes 10 and 16 cm.

The results concerning the size of the gap between the \perp 's original lines did not perfectly conform to my hypothesis, since both the haptic and visual illusions did not decrease in exact proportion to gap size—numerically, they even increased again slightly at the largest gap. Although the percentage values may not have been reliable (no suitable statistical test was available), we should nevertheless consider alternative explanations. One possibility is that the processing mechanisms are different at different retinal eccentricities, which causes illusions first to decline and then to grow larger again. This could be tested by using more and smaller steps for the variation of gap size. Another possibility is that the curvature of the stimulus presentation window acted differently on the two types of lines (cf. Fig. 3): Across gap conditions, it may have been easier to judge the length of the \perp 's upstroke than that of the \perp 's cross-stroke. This idea can be related to the broader study of the effects of different contexts (Armstrong & Marks, 1997; Chapanis & Mankin, 1967; Landwehr, 2015a, 2015b) or, more specifically, of “framing” (Houck, Mefferd, & Greenstein, 1972; Prinzmetal & Gettleman, 1993). The idea is particularly intriguing for the haptic data, since indications for the upstroke hardly differed at all across gap sizes, whereas those for the cross-stroke were critically affected (Fig. 4). For visual trials, a control could be set up by either using a huge projection surface or (better) running the experiment in complete darkness (this would also afford haptic trials).

General discussion

My hypothesis that an expressly drawn T-junction is not necessary for the illusions that commonly go with \perp -type figures received support from all three experiments reported in this article. If one of the endpoints of a linear extent is orthogonally targeting the midpoint of another such extent, the first one will usually appear longer than the latter. The illusion, first described by Titchener (1901) for vision, and about a century later by me for visually mediated haptic signaling (Landwehr, 2009, 2014), survived in dashed, dotted, and dissected \perp s, as it had done in triangles and catenary-derived forms (Landwehr, 2015a, Exp. 3). Not until a gap ≥ 4 deg of visual angle was inserted between the two lines of a \perp were both the haptic and visual \perp illusions markedly reduced. Still, with this two-line stimulus, the \perp 's original upstroke at a vertical orientation was haptically indicated to be reliably longer than the original cross-stroke at an oblique orientation, and visually, it was judged to be longer than the cross-stroke at any orientation.

When I started my research on the \perp illusion (Landwehr, 2009), I suggested that the illusion could possibly be explained in terms of interactions between orientation-sensitive neurons—as was originally proposed by Caelli (1977) to explain length estimates referring to zig-zag lines. Six experiments (plus three controls) later, it has become clear that this cannot be the whole story. Although in Experiment 1 of the presently reported series, local interactions around the virtually conserved T-junction cannot be ruled out, for Experiments 2 and 3, more global interactions would have to be invoked. The generation of the haptic and visual illusions could still be conceived as a process that operates strictly “bottom-up.” That is, the illusions could be thought to be determined by the given conditions of stimulation (cf. Gibson, 1959). A completely different, opposing explanatory scheme is suggested by the visual \perp illusion's survival with the dotted \perp in Experiment 2: The dot configuration as a whole—in a top-down manner—may have driven responses (cf. Wertheimer, 1922, 1923). A similar account was suggested by the illusion's persistence with triangles and catenary-derived forms, in which the figures' heights were not marked by lines (Landwehr, 2015a). Here, an inborn or acquired T-schema could be invoked to do the trick. However, in order to qualify as a testable, neuroscientific hypothesis, the postulation of a Gestalt-type, top-down mechanism would need to be specified (cf. Wagemans et al., 2012). Concerning the figural stimuli, bilateral symmetry might have been what led observers to treat them like \perp s (Landwehr, 2015a). With regard to the dotted \perp , something similar may have been at work, although the dot configuration allows for many different interpretations. In addition to symmetry, or even prior to its detection, a minimum principle might operate to first connect dots according to the shortest distances—necessarily resulting in the notorious \perp -figure. Suitably modifying the figures' shapes and/or the distances in the dot configuration could further illuminate the relative contributions of such subprocesses, some of which may defy an easy classification in terms of bottom-up versus top-down (e.g., the presently mentioned minimum principle; cf. Hatfield & Epstein, 1985; van der Helm, 2000).

Although the gap size effect observed with the dissected \perp in the present Experiment 3 can also be interpreted in terms of the decreasing similarity of the two-line stimulus to a proper \perp (or T), an account in terms of increasingly weakened interactions between orientation-sensitive mechanisms fits the data just as well. Actually, both types of processes may be involved. The case for the orientation sensitivity explanation is supported by my previous observation of an illusion-enhancing effect of parallel lines (Landwehr, 2015a, Exp. 1), and the case for the figural prototype explanation is supported by the observation from the present Experiment 3 that the \perp illusion remained strongest when the \perp 's upstroke was vertically oriented. All in all, then, four mechanisms, at least, have to be considered: a long-range orientation-sensitive

mechanism between parallel lines, a similar mechanism concerning orthogonally oriented linear extents, a figural mechanism (a T-schema), and a mechanism that favors the upright orientation of the \perp 's upstroke. Critical tests of the relative importances of these different processes will include the following: dense regular and irregular patterns of \perp s, in which parallelism of the lines can be varied and in which individual \perp s are bound up in 2- \perp hypermotifs that either optimize or tone down the hypothetical T-schema; irregular patterns of \perp s with multiple orientations of the individual \perp s; and distorted \perp s in which the orthogonality of the lines is broken. Relevant experiments are currently underway and will hopefully clarify matters, insofar as this appears possible through purely psychological means.

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