Opposite haptic and visual induction effects observed with Titchener's $\perp$

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Nineteen psychology undergraduates were requested to "grasp" the lines of a computer image of Titchener's $\perp$ with a thumb and index finger pincer grip immediately after the line to be grasped had been indicated and the whole figure extinguished. The hand remained visible. Lines were of three different lengths (6.5, 7, and 7.5 cm), and $\perp$ s were presented at eight different orientations (rotated in steps of 45°). Lines also had to be judged longer, shorter, or equal, relative to one another. Haptically, subjects responded correctly to the $\perp$ s' undivided lines, but scaled their responses to the divided ones according to the undivided ones. Categorical judgments yielded comparable psychometric functions for both kinds of lines, with a significant shift of points of subjective equality from a difference in length between lines of 9.8% to 13.5% when the divided or the undivided line was target. Haptic sensitivity, therefore, appears to be constrained by context, whereas the classical "visual illusion," associated with Titchener's $\perp$, may be regarded a mere decisional criterion shift.

Visual illusions have long been regarded as a window onto neural processes. During the last two or three decades, much has been made of the often observed discrepancy between these illusions' perceptual effectiveness and their relative irrelevance for motor coordination. Servos, Carnahan, and Fedwick (2000), for example, found considerable visual illusions of lengths, but fairly appropriate grasp responses, with the so-called horizontal-vertical illusion (Titchener's $\perp$ [Titchener, 1901]; cf. Finger & Spelt, 1947), and a similar effect was described by Aglioti, DeSouza, and Goodale (1995) for the Ebbinghaus-circles illusion (although Franz, Gegenfurtner, Bühlhoff, & Fahle, 2000, could not replicate this effect; cf. DeLucia, Tresilian, & Meyer, 2000, p. 565, note to Table 3, for diverging interpretations of Aglioti et al.'s study). The most striking demonstration of the contrast in question probably goes with induced motion: Although subjects vividly experienced a target jumping opposite the displacement of a frame, they still correctly pointed to the target's true position (Bridgeman, Kirch, & Sperling, 1981). These remarkable behavioral dissociations have commonly been viewed consistent with the existence of two functionally distinct systems within visual cortex, one subserving action, the other categorization (Bridgeman, Lewis, Heit, & Nagle, 1979; Goodale & Milner, 1992; Milner & Goodale, 2006; cf. Creem & Proffitt, 2001; Rizzolatti & Gallese, 2006; Trevarthen, 1968; Ungerleider & Mishkin, 1982, for related theorizing).

Results that do not fit this picture were reported by Vishton, Rea, Cutting, and Nuñez (1999). Also utilizing Titchener's $\perp$, these authors succeeded in demonstrating the possibility of both perceptual correctness and motor il-

lusion: Subjects withstood the visual deception when, for metric and analogous judgments, they had been instructed to focus on one line of the display (Experiments 2 and 3), but the same (as well as new) subjects haptically erred with three-finger grasps (Experiment 4, which included a replication of Experiments 2 and 3). On the basis of this evidence, Vishton et al. (1999) suggested that the relevant opposition need not be perceptual judgment versus action, but absolute versus relative size perception.

Several objections can be raised to Vishton et al.'s (1999) work. One problem, mentioned by the authors themselves (p. 1670), is that a three-finger grasp is severely constrained biomechanically. The haptic illusion observed, then, may well have more to do with this inherent difficulty of the motor task than with relational perceptual processing. Furthermore, Vishton et al. used pictorial stimuli that could not really be grasped—subjects merely had to leave ink traces on paper. Goodale, Jakobson, and Keillor (1994, Experiment 3) have argued that such mimed prehension differs from actually laying one's hands on material objects.¹ Smeets and Brenner (1999, 2001), however, provided conceptual grounds—as well as data—suggesting that grasping is nothing more than two-finger pointing (see de Grave, Biegstraaten, Smeets, & Brenner, 2005; Smeets, Brenner, de Grave, & Cuijpers, 2002, for further applications of this model to illusions; the "three-or-more-fingers" case has not yet been analyzed by these authors, but is supposed to be similar). Indeed, pointing responses (if directed at *points*, not objects, as in van Donkelaar, 1999) have typically proven immune to visual illusions *unless* connected with illusions of egocentric localization (Dassonville, Bridgeman, Kaur Bala,

Thiem, & Sampanes, 2004; Gentilucci, Chieffi, Daprati, Saetti, & Toni, 1996; Post & Welch, 1996; Welch, Post, Lum, & Prinzmetal, 2004; cf. Bruno, Bernardis, & Gentilucci, 2008, for additional factors).

At the theoretical level, Vishton et al.'s (1999) proposal does not necessarily contradict the perception–action dichotomy; rather, it supplements it: The absolute–relative distinction applies as well to motor-coordination demands as to descriptions of the stimulus (cf. Vishton & Fabre, 2003, who posed bimanual tasks). Smeets and Brenner's (1999) alternative view of grasping also does not directly undermine the perception–action conjecture, but leads to a thorough reconsideration of the hypothesized systems' properties: If grasping is not based on size perception at all, resistance of an action system to size illusions cannot be due to correct registration of size, but more probably to use of entirely different information (e.g., position information). A straightforward test of the Smeets–Brenner model might compare pointing performance directed at extents that are specified by either continuous lines or distinct dots. Responses should be more precise for the latter type of stimulus. We are currently investigating this prediction with modified Ebbinghaus circles (cf. Rose & Bressan, 2002, for conditions that have to be met for the visual illusion not to vanish).

The purpose of the research presented in this article is more humble: extending the database for the horizontal–vertical illusion. Why should this be important? There are several limitations to the studies of Servos et al. (2000) and Vishton et al. (1999), the only studies that used Titchener's $\perp$ in the context of the two visual systems' debate. Servos et al.'s grasping trials included two different $\perp$ s with identical verticals. In several of Vishton et al.'s experiments, only $\perp$ s with lines of equal lengths were used. This lack of variation cannot be compensated by repeated trials; on the contrary, it invites effects of learning. Second, stimuli were always presented at a single orientation. This means that if both lines are to be grasped, grasps will occur at different places, and if the whole figure is centered midsagittally, grasps are difficult in different ways. Indeed, Servos et al. (2000, pp. 402–403) observed a significant *inverse* haptic horizontal–vertical illusion (completely ignored in the abstract and the discussion section of their article), which they explain by the horizontal reaches' awkwardness. Conversely, in a partial replication of their Experiment 1, Vishton et al. (1999, "secondary procedure") observed nearly perfect grasps of the $\perp$'s verticals, and undershooting of the horizontals—an interesting asymmetry that the authors did not dwell on in their general conclusions.

Methodologically, we conform to Vishton et al.'s (1999, pp. 1660–1661) criticism of Aglioti et al. (1995), who, in turn, did *not* adhere to the following desiderata (cf. Haffenden & Goodale, 1998, for reply): (1) In studies of visually initiated haptic behavior, there should not be any tactile feedback;² (2) all haptics should be open loop; (3) haptic performance should not be impeded by obstacles; (4) stimuli should be of comparable dimensionality throughout; (5) the relevant dependent haptic measure is grip aperture at the end of the reach. Arguments (1), (4), and (5) justify

use of pictorial stimuli and mimed grasping (or pointing). Argument (3) leads one to prefer Titchener's $\perp$, or any other obstacle-free figure, against, for example, the Ebbinghaus-circles illusion (see Stöttinger & Perner, 2006).³ Because of insufficient equipment, we could not comply with argument (2). Instructing subjects to close their eyes before starting to reach (as done by Vishton et al., 1999) is likely to result in delayed responding, and hence may introduce a memory confound; see Westwood, Heath, and Roy (2000) for estimates of relevant reaction times (RTs). Instead, we introduce a new paradigm that can be considered an alternative to the standard obstruction-of-view technique (cf. Westwood & Goodale, 2003, for concerns about possible effects of that technique). Our stimuli, after a fixed presentation time, simply vanish, and, haptically or judgmentally, subjects have to respond at this very moment, while their hands remain in view. Although Vishton et al. suspect that visual illusions might exert a critical effect during the final phase of the action taken toward them, visibility of one's hand may not pose a crucial problem for our procedure, because (for haptic responding) during the reach there is nothing left that one's grip aperture could be compared with; see Goodale, Péllisson, and Prablanc (1986), who demonstrated online corrections of reach trajectories toward displaced targets for the *unseen* hand—which demonstration suggests that sight of one's hand is not necessarily involved in the control of grasping behavior (cf. Bruno et al., 2008, pp. 430–431).

As already indicated, our present work is not intended as a direct test of any of the theories cited above, all of which make similar predictions: Haptic responses to individual lines of Titchener's $\perp$ will be fairly correct, but visual judgments of relative lengths of lines will be erroneous (Milner & Goodale, 2006; Smeets & Brenner, 1999; Vishton et al., 1999). Our main interest is in the explanation of visual illusions as such—the horizontal–vertical, in particular. Yet, as we shall see, our results partially contradict presently cited predictions and hence do have implications for any theory of motor coordination or, for that matter, of perception–action dissociation. With regard to our illusion figure, it has long been known that Titchener's $\perp$ is *not* a pure case of horizontal-versus-vertical orientation. As convincingly demonstrated by Künnapas (1955), who gradually transformed Titchener's $\perp$ into Sanford's $\perp$ ([Sanford, 1898]; Finger & Spelt, 1947), the major factor seems to be division of one line by another. Indeed, after having presented singular lines in total darkness, Verrillo and Irvin (1979, p. 270) had to conclude that "when care is taken to eliminate [all kinds of contextual] cues . . . , the Horizontal–Vertical Illusion does not exist." Still, with minimum context—or if lines are combined—orientation *does* matter (Armstrong & Marks, 1997; Avery & Day, 1969; Pollock & Chapanis, 1952; Shipley, Nann, & Penfield, 1949). We therefore presented Titchener's $\perp$ at eight different orientations; curiously, this does not seem to have been done before. We expected the illusion to be strongest when the undivided line was oriented vertically, because at this orientation the horizontal–vertical and the divided-line effects would combine (Finger & Spelt, 1947; Künnapas, 1955). Oblique orientations of the stimulus figure would

produce an attenuated effect by isolating the divided-line effect and thereby eliminating the horizontal-vertical component. Horizontal orientation of the undivided line of Titchener's $\perp$ would yield the weakest illusion, because at this orientation the horizontal-vertical and the divided-line effects would act against one another.

METHOD

Subjects

Nineteen undergraduate students of psychology participated. Visual trials could not be recorded for two of them. All subjects were right-handed and had normal or corrected-to-normal vision.

Apparatus

For subjects, visible apparatus consisted of a computer screen (size: 38.5×31 cm; resolution: $1,280 \times 1,024$ pixels), set flush into a table (62×62 cm) and covered by a reduction screen, leaving a circular window (diameter 29 cm; plane visual angle: $38^\circ \times 33.5^\circ$), which served as a presentation area and as a working area for haptic trials. For visual trials, a modified numerals keyboard covered with cardboard so as to leave only digits 1, 2, and 3 visible, was put on the table next to the marked resting positions of subjects' dominant hands during haptic trials (this position was, orthogonally, 25 cm from the screen's center, and elevated by 2 cm to make for reliable data recording; resting positions of thumb and index finger were spaced 8 cm apart). Surrounding the table, three cameras of a movement tracking system (Qualisys Motion Capture Systems, Gothenburg, Sweden) had been positioned. During haptic trials, subjects wore infrared-sensitive markers at their thumb and index finger so that interdigit distances and movement trajectories could be captured. Recording was at 60 Hz. Computerized stimulus presentation was controlled by Presentation software of Neurobehavioral Systems, Inc., Albany, CA.

Stimulus Materials and Response Measures

For haptic baseline trials, the stimulus was a single black line (width: 0.6 mm; maximum contrast against a plain white background of 45 cd/m^2). Three different lengths (6.5, 7, and 7.5 cm, ranging in visual angle between 9° and 10° horizontally, and 8° and 9° vertically) were presented at two different orientations (45° and 90° ; other orientations were discarded because of awkward grasp postures; see our remarks at the beginning of this article re: Servos et al.'s, 2000, work). For the first set of 30 trials (fivefold repeated measurement), lines stayed in place for 3 sec, and subjects were requested to respond within this time limit by grasping the line with a thumb and index finger pincer grip. For the second set of 30 trials, lines stayed in place for 2 sec. Their color turned red for 200 msec, then turned black again for another 200 msec, then lines vanished.⁴ Subjects had to respond instantaneously at this moment. Interstimulus interval was 2.4 sec for the first condition and 3 sec for the second one, making for equal trial durations. The blinking procedure in the second set of baseline trials was introduced because we needed a nonverbal cue to instruct subjects which line of Titchener's $\perp$ we wanted them to grasp during experimental trials. Pretest had shown that a black-and-white blinking did not work reliably, so we had to use color instead.

For haptic and visual experimental trials, the stimulus was Titchener's $\perp$, with lengths of lines varied so as to yield all possible combinations of the lengths used during haptic baseline measurements. All nine figural variants were shown at eight different orientations, making for 72 unique trials per block, ordered randomly. $\perp$ s were rotated around the midpoint of the line to be grasped or judged—which line, again, was indicated by blinking (see note 4). Responses were directed at the divided line for orientations 45° , 90° , 225° , and 270° , and at the undivided one for 0° , 135° , 180° , and 315° (angle measures refer to the divided line). For the reasons mentioned in the preceding paragraph, we could not avoid this confound: There simply is no orientation of Titchener's $\perp$ that affords a comfortable

grasp of both of its lines unless both hands are used, and even then the horizontally oriented line remains difficult to grasp. Note, however, that in our experiment all vertical and all diagonal grasps, respectively, occur at identical places.

For visual trials, a blinking line's length had to be judged *shorter* (coded 3), *equal* (2), or *longer* (1), relative to the other one (code numbers had been chosen to counter suggestive ordinal ranking). The four parts of the experiment—two sets of haptic baseline measurements (2×30 trials) and two sets of experimental trials (one haptic, one visual; 2×72 trials)—were always run in the same sequence in one session that lasted between 30 and 45 min. There were two reasons why the sequence of blocks was not counterbalanced. Baseline trials had to precede experimental trials because we wanted motor responses to stabilize, and also because we had to introduce our blinking technique. Furthermore, prestudies in our laboratory had shown an influence of visual judgments on haptic performance, but not the reverse (Ehlert, Schulz-Eppens, Stoll, & Landwehr, 2007).

Design

Stimuli and responses make for a twofold (divided vs. undivided line of Titchener's $\perp$) 3 (length of divided line) $\times 3$ (length of undivided line) $\times 4$ (angular orientation of stimulus figure) design. The design was completely within, and trials from its two parts were interleaved at random.

Procedure

Subjects were shown a single black line (length, 8 cm; width and contrast roughly equivalent to electronically created stimuli) centered on a plain white square sheet of paper (21×21 cm) and were asked to grasp that line. If subjects did not volunteer to grasp the line at its endpoints by means of a thumb-and-index-finger pincer grip, they were told to do so and practice this kind of grasping five times. Next, Titchener's $\perp$ (similarly constructed) was presented, but not grasped. All subjects were acquainted with the figure and the illusion that commonly goes with it. Subjects were asked not to let this knowledge influence their responses during the experiment.

Preanalysis of Haptic Data

Interdigit distances at the end of reaches were determined algorithmically by finding, after up-down coordinates of both thumb and index finger had fallen below 0.5 cm, four frames across which these coordinates did not change in excess of 0.2 mm. Since infrared markers had been fixed to subjects' fingernails, measured interdigit distances were always greater than the ones intended. We reasoned that measured distances for visible lines would reflect intended placement of fingertips, plus error due to marker positions; for vanishing lines, these variables, plus error due to our "blank-out" procedure. As the main experiment would also use the vanishing technique, haptic measures of experimental trials were corrected by subtracting overshoots seen in the second set of baseline measurements from corresponding measures obtained with $\perp$ stimuli.⁵

RESULTS

Haptic Data

Comparison of our two baseline conditions allows us to estimate the effect of our blank-out, or vanishing-stimulus, procedure, and hence of the RT delay introduced by that procedure. Responses became more variable, and means were larger, when the stimulus could no longer be seen. This is in agreement with previous observations (e.g., Wing, Turton, & Fraser, 1986). A repeated measures ANOVA, however, only showed significant main effects of length and angular orientation of lines [$F(2,17) = 48.245, p < .000, \eta_p^2 = .728, F(1,18) = 15.686, p < .001, \eta_p^2 = .466$]; baseline condition was merely involved in a

three-way interaction with these two variables [$F(2,17) = 5.068, p < .012, \eta_p^2 = .220$]. The implication that subjects could discriminate lengths of lines under offline condition almost as well as online is supported by a separate analysis of the second baseline condition [$F(2,17)_{\text{length}} = 32.739, p < .000, \eta_p^2 = .645$; $F(1,18)_{\text{orientation}} = 2.598, p < .124, \eta_p^2 = .126$]. The effect of angular orientation of lines is less easily understood. It could either be an artifact of our measurement technique or else reflect a difference in difficulty of grasps at different orientations; in any case, effects of this variable, for the main experiment, must be treated with caution.

For haptic experimental trials, averaged regression equations for reproduced to actual lengths of lines were $0.609x + 2.51$ for the divided line of Titchener's $\perp$, and $0.909x + 0.664$ for the undivided one.⁶ This indicates that the undivided line was responded to much more correctly than was the divided one, which was increasingly undershot with increasing length [slopes tested against 1: $t(18) = -2.317, p < .016$ (one-tailed), $d = 0.532$; $t(18) = -5.469, p < .000, d = 1.255$]. More importantly (as shown in Figure 1, which displays means and 95% confidence intervals of haptic reproductions separately for the two types of lines, plotted against one another), responses to the undivided line remained unaffected by the length of the divided one [$F(2,36)_{\text{divided line}} < 1$; $F(2,36)_{\text{undivided line}} = 157.337, p < .000, \eta_p^2 = .897$], whereas, conversely, increasing length of the undivided line induced an increase in finger span relating to identical lengths of the divided line [$F(2,36)_{\text{divided line}} = 57.119, p < .000, \eta_p^2 = .760$; $F(2,36)_{\text{undivided line}} = 14.716, p < .000, \eta_p^2 = .450$]. Interestingly, this haptic "induction effect" is opposite to the one typically observed for vision (Obonai, 1954).

In order to arrive at an overall measure of illusion, grand means were computed and tested against their expected values of 7 cm. For the divided line, the mean was 6.773 cm, equivalent to a 3.241% illusion [$t(683) =$

$-9.688, p < .000, d = 0.370$]; for the undivided line, the mean was 7.030 cm, equivalent to a 0.428% illusion [$t(683) = 1.246, p < .213, d = 0.048$]. Angular orientation of the stimulus did not exert any influence for either line [$F(3,54)_{\text{divided line}} = 2.431, p < .107, \eta_p^2 = .119$; $F(3,54)_{\text{undivided line}} < 1$].

Visual Data

On the face of it, the $\perp$ -illusion worked impressively well: There were few *longer* judgments for the divided line, and few *shorter* judgments for the undivided one. In terms of right or wrong, the three stimuli for which the divided line was shorter than the undivided one were generally responded to correctly, and those for which the divided line was longer than the undivided one, incorrectly. With the three stimuli where both lines were of equal length, the proportion of correct to incorrect responses did not differ from chance for the divided line, but did so significantly for the undivided one (all binomial $ps < .002$; g ranging between .19 and .32).

Approximating data by psychometric functions revealed similar slopes for *shorter* judgments of the divided line and *longer* judgments of the undivided one, suggesting that visual sensitivity to differences in length did not differ for the two types of lines (cf. Morgan, Hole, & Glennerster, 1990). Functions were displaced relative to one another, though, and points of subjective equality (in terms of divided minus undivided line) were found at 0.685 cm for the divided line as target and at 0.945 cm for the undivided line, corresponding to illusion magnitudes of 9.8% and 13.5%, respectively (referred to 7 cm as standard).

Since our visual task was one of *relative* judgment, it appeared desirable to analyze possible effects of angular orientation of the stimulus for all orientations together. *Same* responses peaked at 90° and 270° , where the undivided line was oriented horizontally; and at 0° and 180° ,

Figure 1. Means and 95% confidence intervals of haptic responses to the different lines of Titchener's $\perp$ plotted against lengths of nontarget lines. $\blacktriangle$ = 6.5 cm; $\bullet$ = 7 cm; $\blacksquare$ = 7.5 cm.

where the undivided line was oriented vertically, the number of these responses dropped considerably [$\chi^2(7, N = 1,224) = 43.514; p < .001; w = 6.597$]. This effect size, although small, reestablishes Titchener's $\perp$ as a case of horizontal-vertical illusion, with responses directed at the obliques ranging between the cardinal orientations (Avery & Day, 1969; Künnapas, 1955).

DISCUSSION

As far as our findings agree with what was previously observed in comparable research, they can be cited as support for the theories referred to at the beginning of this article. Some of our results, however, are difficult to reconcile with these accounts. In particular, the haptic induction effect we found is not predicted by any version of the two-visual-systems theory. Similarly, the different amount of visual illusion in Titchener's $\perp$ for divided versus undivided line is not predicted by Vishton et al.'s (1999) absolute versus relative perception view. Both effects, though, at least for the stimulus parameters used in our experiment, can possibly be explained in terms of local interactions within the neural substrate (cf. Caelli, 1977). At the T-junction of Titchener's $\perp$, orientation detectors for the divided line might be inhibited by a termination detector for the undivided line, leading to apparent shortening of the divided line. Conversely, as the length of the undivided line is increased, orientation detectors related to this line might inhibit the initially inhibiting termination detector, giving way to apparent lengthening of the divided line.

Beyond this, a basic riddle remains: Why would perceptual mechanisms develop that systematically misinform the observer? Titchener's $\perp$, in our experiment and as in most others before, was presented in isolation (but cf. Künnapas, 1955, who tested a double $\perp$). It is quite possible that such impoverished stimulation taxes the response systems' capacities more than a richer environment would do (Gibson, 1979). We therefore plan to test the generality of our present findings with more complex stimuli, embedding Titchener's $\perp$ into patterns and branching structures. Maybe all illusions will vanish within a forest of $\perp$ s (cf. Chapanis & Mankin, 1967; DeLucia & Hochberg, 1991).

AUTHOR NOTE

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NOTES

1. The notion of (panto)mime is used in two different meanings in this discussion, referring to "as-if grasping" and "grasping from memory," respectively (DeLucia et al., 2000, Experiment 4; Goodale et al., 1994, Experiments 1 and 2; Westwood, Chapman, & Roy, 2000).
2. It appears useful to distinguish between *tactile perception*, mediated by receptive structures in the skin, and *haptic perception*, mediated, in addition, by receptors at the joints and muscles. Plain haptic perception (and behavior) obtains when the limbs are moved without contact with any substrate—although some stimulation of Ruffini structures can never be completely excluded (see Wolfe et al., 2006, chapter 12).
3. A separate discussion developed around this issue (Franz et al., 2000; Haffenden & Goodale, 2000; Haffenden, Schiff, & Goodale, 2001). We concur with Franz, Bühlhoff, and Fahle (2003) that obstacle avoidance cannot explain the differences in grasping performance observed by these two research teams and others. The topic remains of concern nonetheless (de Grave et al., 2005; Dewar & Carey, 2006).
4. Subjectively, the change in chromaticity, as described, is experienced as "blinking" (≈ 2.5 Hz), and will be referred to as such in the following.
5. Since overshoots differed not only between subjects but also in terms of the length and angular orientation of lines, we computed six individual correction values per subject and condition, averaging only across the fivefold repeated measurement.
6. Analysis by means of linear mixed models yielded comparable estimates of weighting factors (divided line: 0.593; undivided line: 0.915).

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