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Perceiving the Present: Systematization of Illusions or Illusion of Systematization?

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Abstract

Mark Changizi et al. (2008) claim that it is possible systematically to organize more than 50 kinds of illusions in a 7 × 4 matrix of 28 classes. This systematization, they further maintain, can be explained by the operation of a single visual processing latency correction mechanism that they call ''perceiving the present'' (PTP). This brief report raises some concerns about the way a number of illusions are classified by the proposed systematization. It also poses two general problems—one empirical and one conceptual—for the PTP approach.

Keywords: Illusions; Systematization; Visual prediction; Extrapolation; Sensorimotor contingencies; Compensation; Neural delay; Perceiving the present

1. Introduction

The proverbial fox knows many things, but the hedgehog knows one big thing. When it comes to visual illusions, traditional researchers tend to be foxes. They tend to accept what Coren, Girgus, and Day (1973) describe as ''the nonparsimonious and esthetically ugly position'' that visual illusions are ''multiply caused and maintained by a number of different peripheral and central factors'' (p. 504). Efforts to taxonomize, that is, systematically classify, visual illusions, must comport with this constraint.[1]

Mark Changizi and co-authors have recently made an ambitious and unprecedented case in this journal for what might be called the hedgehog's point of view (Changizi, Hsieh, Nijhawan, Kanai, & Shimojo, 2008). Not only do they argue that it is possible to organize more than 50 seemingly disparate kinds of visual illusions in a 7 × 4 matrix of 28 illusion classes, they also hypothesize that a *single* visual information processing

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mechanism may adequately explain all of the illusions taxonomized by their scheme. The bold and undeniably original theory that they put forward is summarized by the following six claims:

I. The human visual system compensates for the visual processing latency (VPL) between proximal stimulation and perceptual awareness during forward locomotion by predictively generating a conscious perception of the next probable scene. Latency correction mechanisms make it possible for moving observers to *perceive the present* instead of the recent past.
II. Certain stimulus features are statistically correlated with a moving observer's direction of motion (DoM). A region of the visual field near the DoM will tend to have the following: (1) smaller angular sizes; (2) smaller angular speeds; (3) greater luminance contrasts; (4) greater distances; (5) lower eccentricity; (6) smaller angular distances from the vanishing point of converging lines; and (7) smaller angular distances from the focus of expansion (FoE). In what follows, I shall refer to these putative cues to the observer's DoM as ''M-features.''
III. Targets that have a smaller angular distance from the moving observer's DoM will tend to undergo: (A) greater increase in angular size; (B) greater increase in angular speed; (C) greater decrease in luminance contrast; and (D) greater decrease in distance.
IV. Combining ''DoM'' regularities 1–7 in (II) and ''rate of change'' regularities A–D in (III) results in 28 higher-order regularities, 1A–7D, concerning the way a target's perceived features change during forward motion as a function of its angular distance from the DoM. For example, combining regularities 1 and A yields regularity 1A: ''A region of the visual field with smaller angular sizes tends to undergo in the next moment a greater increase in angular size.''
V. Visual illusions arise when a stationary observer is presented with a stimulus containing one or more of the M-features mentioned in (II). In such a case, the stimulus ''tricks'' the visual system into thinking that the observer is moving forward and, so, given (I), into compensating for the VPL by generating a conscious perception of the way target would project in the next moment.[2] Visual illusions are cases of ''inappropriate'' perceiving of the present.
VI. Last, to each of the 28 empirical regularities mentioned in (IV) there corresponds a predicted class of visual illusions (see the illusion evidence table on pp. 477–480).

The combination of these six claims is an ambitious new theory of visual illusions motivated by an impressively varied array of psychophysical evidence. Although complete, case-by-case assessment of the way illusions are classified by Changizi et al. (2008) is obviously not possible in the space of this brief report, I raise some concerns in what follows about the way a number of illusions are treated by the proposed systematization.[3] I also pose two general problems—one empirical and one conceptual—for the PTP approach. I begin with these in the next section.

2. M-features and direction of movement

Changizi et al. (2008) point out that DoM regularities 2, 3, 5, 6 will not necessarily obtain unless it can be assumed that forward-moving observers *tend to fixate on objects near the DoM* (p. 466).[4] This assumption, however, seems quite questionable. For example, when traversing a forest trail, or a city sidewalk, or even an empty beach, our eyes and head move continuously, and the direction of gaze seems only intermittently to correspond to the DoM (Bruce, Greene, & Georgeson, 2003, p. 340). The reader is invited to inspect her own pattern of eye movements in everyday walking.

In support of the assumption that ''lower eccentricity tends to correlate with heading'' (p. 466), the authors cite studies by Wann and Swapp (2000) and Wilkie and Wann (2003). These studies, however, do not deal with the pattern of fixation in low-velocity walking, but rather in high-velocity *driving* on curvilinear paths. Moreover, the studies actually found that observers visually track points on their future path that are *eccentric* to their instantaneous DoM; that is, they found that lower eccentricity does *not* tend to correlate with heading (also see Wann & Land, 2000 and Wilkie & Wann, 2006).

More relevant studies of visual guidance of locomotion on foot (Harris & Rogers, 1999; Rushton & Harris, 2004; Rushton, Harris, Lloyd, & Wann, 1998) also fail to corroborate the assumption that lower eccentricity is well correlated with heading. In particular, they provide evidence that pedestrian observers utilize the perceived, egocentric location of the target relative to the bodily midline, that is, the locomotor axis, rather than the FoE of optic flow. In order to correct deviations in heading (reflected in target drift), walking observers need only intermittently fixate on the intended DoM so as to align their bodily midline with the orientation of their eyes and head. Notably, Harris and Bonas (2002) found that even when scene structure and optic flow information are available in addition to information about the target's egocentric direction, visual guidance of human walking may rely only on the egocentric direction strategy.

In addition to this empirical problem, the PTP approach also faces a conceptual problem. Changizi et al. (2008) do not only assume that M-features mentioned in regularities 1–7 (see II above) are cues to the direction in which a *moving* observer is traveling. They also assume that each of the M-features is by itself a sufficiently reliable indicator of *forward movement* that its presence in a stimulus array can cause latency correction mechanisms to generate a perception of the next probable scene. The presence, however, of an angular size, luminance, or velocity gradient in the visual field, as the authors themselves note (p. 467), is fully consistent with *stationary observation*. Indeed, the majority of ecologically normal stimuli confronting a stationary observer would seem to contain at least one (and usually more than one) of the features that the authors take to indicate forward movement in a certain direction.[5] In order adaptively to interpret the presence of an M-feature as a DoM cue, then, the visual system would seem to require independent kinaesthetic/proprioceptive evidence (e.g., from efference copy, muscle stretch, optic flow, etc.) that the observer was actually in motion. But, if this is the case, then it seems quite implausible that illusion stimuli should, by themselves, that is, in the absence of such additional evidence, cause the visual system to engage in inappropriate latency correction—contrary to the PTP hypothesis.

3. Illusions and empirical regularities 1A–7D

To each of the 28 empirical regularities (1A–7D) described by Changizi et al. (2008), there corresponds a *predicted class* of visual illusions. Of the 28 predicted classes, three are empty: 4B, 4C, and 7C. In this section, I assess the empirical tenability of the way a variety of illusions are classified by 8 of the remaining 25 empirical regularities: 1A, 1B, 3A, 3D, 4A, 4D, 6A, and 6C. I select these examples in particular for examination because they are among the more familiar and widely studied illusions taxonomized by the authors.

(1A) ''A region of the visual field with smaller angular sizes tends to undergo in the next moment, that is, the predicted perception is of, a greater increase in angular size.'' According to the authors, 1A characterizes traditional *size-contrast* illusions such as the Ebbinghaus (Titchener Circles) illusion (p. 472). There are several problems, however, with this classification of the Ebbinghaus illusion. First, inducers with larger angular sizes in the annulus surrounding the target usually result in *underestimation* of the target's size. 1A does not predict this effect—arguably one half of the illusion. Second, there is evidence that a number of other stimulus variables besides relative size significantly contribute to the magnitude of the illusion (Franz & Gegenfurtner, 2008; Roberts, Harris, & Yates, 2005). These include the *completeness* of the inducing annulus and the structural *similarity* of the inducers to the target (Choplin & Medin, 1999; Rose & Bressan, 2002). While the PTP approach presumably predicts that increasing the distance of smaller inducers from the target should attenuate the overestimation of the target's apparent size (by DoM regularity 5), 1A is not consistent with the finding that smaller inducers can actually cause underestimation of the target's size as distance increases (Girgus, Coren, & Agdern, 1972; Roberts et al., 2005). Recent studies by Roberts et al. (2005), in fact, show that the general tendency of surrounding inducers is to *reduce* the apparent size of the target, even when the inducers are comparatively smaller in angular size. They conclude that the standard size-contrast interpretation of the Ebbinghaus illusion is an oversimplification: ''it would be more appropriate to conclude that inducers generally reduce apparent target size and that small inducers are simply less effectual in doing this'' (Roberts et al., 2005, p. 850).[6]

(1B) ''A region of the visual field with smaller angular sizes tends to undergo in the next moment a greater increase in angular speed.'' The authors here cite studies that have found that a moving target is perceived as faster when traveling against a background with smaller features (Brown, 1931; Gogel & McNulty, 1983; Johansson, 1950) or greater dot densities (Watamaniuk, Grzywacz, & Yuille, 1993). It is plausible, however, that the perceived speed of a moving target rather increases against backgrounds with greater texture densities because such backgrounds provide more *visual reference marks* with which to assess relative motion (Gogel & McNulty, 1983).[7] Notably, Nguyen-Tri and Faubert (2007) found that, in contrast with static texture, the presence of *dynamic* texture does not increase perceived speed. This lends support to the idea that texture must provide ''reliable spatial landmarks'' in order to produce an increase in the target's perceived speed. Mere proximity to a background texture, as suggested by 1B, is not sufficient to produce an increase in perceived speed. Another possibility is that the increase in perceived speed is the result of an increase in the moving target's *visibility* on textured backgrounds (Blakemore & Snowden, 2000;

Snowden, 1997). One piece of evidence for the latter hypothesis is that changes in perceived speed due to target contrast (the ''Thompson effect'') are eliminated when the target moves across a textured background, but they are reinstated when the target is provided with a narrow, untextured alleyway over which to travel (Blakemore & Snowden, 2000). Low-contrast targets are ''corrected'' with respect to their perceived speed, Blakemore and Snowden suggest, because the background texture increases the visibility of the target's outline. Given the strong empirical plausibility of these theoretical alternatives, there is good reason to think that the putative M-feature mentioned in 1B, that is, smaller angular sizes, plays a role in causing the illusory motion effect that is independent of any statistical link between that feature and a walking observer's DoM.

A second problem with classification by regularity 1B is conceptual. In particular, in cases in which a putative M-feature is a property of the surround as a *whole*—as in the case of fine background texture or high dot density—there is no region of the visual field that can be singled out by appeal to the relevant DoM regularity as the region toward which the observer is probably moving. But this means that there is no region of the visual field that can be nonarbitrarily singled out as the region that will undergo the changes respectively predicted by rate-of-change correlates A–D. In the cited study by Watamaniuk et al. (1993), for example, it was found that increasing dot density in a random dot cinematogram produced a *global increase* in perceived speed, that is, for the whole array. In this case, there is neither a single region of the visual field that can be associated with the observer's probable DoM, nor a single region of the visual field that instances the illusory motion effect.

(3A) ''A region of the visual field containing greater luminance contrasts tends to undergo in the next moment a greater increase in angular size.'' Box 3A of the illusion evidence table cites studies that have found that greater luminance contrasts enhance the classical geometrical illusions and that (color) equiluminance eliminates them (Lehmann, 1904; Liebmann, 1927; Livingstone & Hubel, 1987). Putting aside the objection that many geometrical illusions involve a *decrease* in angular size, for example, the Ebbinghaus illusion with large inducers or the ''wings-in'' version of the Müller–Lyer illusion, I shall merely point out here that more recent studies have found that many geometrical illusions are robustly sustained under equiluminance (Cavanagh, 1986, 1989; Gregory, 1977, 1979; Li & Guo, 1995). Indeed, the most comprehensive and carefully controlled study of the issue to date by Hamburger, Hansen, and Gegenfurtner (2007) found that nine of the best known geometric illusions (Delboeuf, Ebbinghaus, Hering, Judd, Müller–Lyer, Poggendorff, Ponzo, Vertical, and Zöllner) were as strong when presented under two different equiluminant chromatic contrast conditions as when presented under luminance contrast. The best current psychophysical evidence thus suggests that the class of visual illusions predicted by 3A does not exist.

(3D) ''A region of the visual field containing greater luminance contrasts tends to undergo in the next moment a greater decrease in perceived distance.'' As an example of an illusion falling under 3D, Changizi et al. (2008) refer to what they describe as a new illusion predicted by the PTP approach (see the figure on p. 478). In the illusion, the left end of a uniformly grey rectangle appears closer in depth because of the higher contrast surround on the left. There is a more straightforward explanation of the illusory effect, however. If luminance contrast is necessary to compute depth from occlusion and, so, to segment surfaces located at different depths, as influentially argued by Livingstone and Hubel (1987), then the left end of the rectangle may appear to be closer because it is perceived partially to *occlude* the two darker rectangles on that side: Surfaces that are perceived as occluders appear by definition to be closer than the surface(s) that they appear to occlude. Since the right end of the rectangle, by contrast, is in a low-contrast region of the stimulus array, the appearance of occlusion is much less pronounced. This parsimonious alternative explanation would seem to obviate appeal to the putative correlation between lower luminance contrasts and the observer's DoM under conditions of forward locomotion.

(4A) ''A region of the visual field containing greater distances from the observer tends to undergo in the next moment a greater increase in angular size.'' Box 4A of the illusion evidence table cites studies that have found that depth information provided by stereopsis, accommodation, and convergence can modulate perceived size. In particular, when viewing two targets at different distances that subtend the same visual angle under reduced cue conditions, that is, in the absence of depth information provided by perspective, texture gradients, occlusion, shading, etc., observers paradoxically perceive the far target as both *larger* and *closer* than the near target (Biersdorf, Ohwaki, & Kozil, 1963; Epstein, Park, & Casey, 1961; Gogel 1978; Heinemann, Tulving, & Nachmias, 1959; Kaneko & Uchikawa, 1997; McCready, 1985; Mon-Williams & Tresilian, 1999; Ono, Muter, & Mitson, 1974). This phenomenon is commonly known as the ''size-distance paradox.''

The increase in the target's perceived size (in notable contrast with the decrease in its perceived distance) in the ''size-distance paradox,'' however, is relatively unmysterious. In fact, it can be predicted from Emmert's law, according to which perceived size increases with perceived distance in depth (Emmert, 1881). Under reduced cue conditions, stereopsis, accommodation, and vergence are important cues to the distance of a binocularly viewed target. Emmert's law therefore predicts that increasing the target's perceived distance by increasing its stereoscopic-, accommodative-, or vergence-specified distance should lead to a corresponding increase in the target's perceived size.[8] If this is the case, however, then the correlation between the putative M-feature, that is, greater distances, and the DoM under conditions of forward locomotion again seems extraneous to characterizing and explaining the illusory effect in question.

(4D) ''A region of the visual field containing greater distances from the observer tends to undergo in the next moment a greater decrease in perceived distance.'' Box 4D concerns illusions of depth contrast, in which the perceived depth or slant of a surface is modulated not only by binocular disparities with respect to the surface itself but also by disparities with respect to flanking and surrounding surfaces (see Howard & Rogers, 1995 for a review). Thus, it has been found that when a target strip in the frontal plane is presented against the background of an inclined surface, the target appears inclined in the opposite direction, that is, toward the observer (van Ee, Banks, & Backus, 1999; Sato & Howard, 2001; Werner, 1937). This effect has been termed ''slant contrast'' (van Ee et al., 1999).

The ''slant estimation'' theory put forward by van Ee et al. (1999), however, seems to explain this effect quite well. The theory is premised on the idea that surface slant is computed using a weighted, linear combination of various slant estimators. The target appears to slant in the opposite direction to that of the inducer, according to the theory, because the absolute slant of the inducer as well as the relative slant between target surface and the inducer are both estimated with greater reliability and, so, are proportionally weighted more heavily than the absolute slant of target. One important merit of the slant-estimation theory is that it correctly predicts that when stereo-based and perspective-based signals specifying the inducer's slant are mutually consistent (which is not the case when the stimulus consists of images on a display screen, but is the case when the stimulus consists of real planes) the slant-contrast effect will be eliminated. It also correctly predicts a *reversed* slant contrast effect, that is, the target's apparent slant in the opposite direction (away from the observer), when the inducer's stereo-specified slant is zero but its nonstereo-specified slant is non-zero. Regularity 4D does not equip the PTP approach, however, to predict either of these results. Indeed, the latter result is inconsistent with 4D.

(6A) ''A region of the visual field containing smaller angular distances from the vanishing point of converging lines tends to undergo in the next moment a greater increase in angular size.'' According to Changizi et al. (2008), empirical regularity 6A unifies a large menagerie of classical geometrical illusions. This is decidedly the most ambitious application of the PTP approach. In what follows, I focus in particular on the way the PTP approach deals with the Müller–Lyer and Ponzo illusions.

One difficulty is that 6A does not predict that the central line segment in the familiar ''wings-in'' version of the Müller–Lyer stimulus will be underestimated. And it also seems inconsistent with the observation that the central line segment is underestimated in the ''wings-out'' version when the wings are outwardly displaced (Oyama, 1960; Predebon, 1994). Another basic difficulty is that there are well-known 2-D and 3-D variants (DeLucia & Hochberg, 1991; Nijhawan, 1991) of the Müller–Lyer stimulus that do not contain oblique, 2-D line segments. A rigorous theory of the Müller–Lyer illusion, as Nijhawan (1991) has argued, ''must be general enough to explain the illusion found in all of these variations, as well as others that exist too'' (p. 315). The PTP approach, however, is not able to account for these variants of the Müller–Lyer illusion in terms of empirical regularity 6A.[9]

The PTP approach similarly presupposes that oblique, 2-D line segments in the stimulus are necessary for the Ponzo illusion. The Ponzo illusion, however, is sustained when the horizontal line segments are presented on a 3-D truncated pyramid, viewed from above (Prinzmetal, Shimamura, & Mikolinski, 2001, p. 109; Rock, 1984, p. 156). It is also sustained when the inducing elements are replaced with an illusory triangle (Farnè, 1968); with two pairs of short vertical lines, one pair surrounding each horizontal bar (Fisher, 1973); with a single, oblique line segment (Fisher, 1968a); or with a triangular arrangement of dots (Kanizsa, 1974).[10] 6A, however, does not cover any of these variants of the Ponzo illusion.

Last, criticisms of the linear perspective theory of the Ponzo illusion by Prinzmetal et al. (2001) also apply to the PTP approach. In an experiment designed to compare the predictive merits of the linear perspective theory and the ''tilt constancy'' theory (Prinzmetal & Beck, 2001; Shimamura & Prinzmetal, 1999), Prinzmetal and co-authors devised three stimulus conditions (Fig. 1). In all three conditions, the vertical line segments are physically identical in length. Both the linear perspective theory and the PTP approach agree with the tilt constancy theory in predicting that the vertical line on the right in Condition 1 will appear longer in length than the vertical line on the left. This, of course, is the classical Ponzo

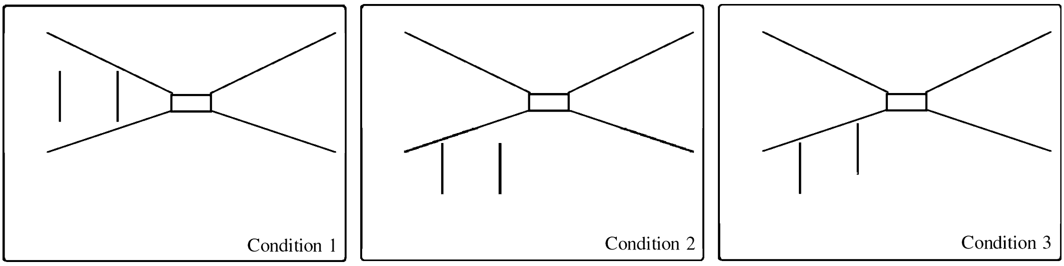

Fig. 1. Three stimulus conditions used in an experiment designed to compare the predictive merits of the linear perspective theory and the tilt constancy theory. Adapted from Prinzmetal et al. (2001).

illusion. In Condition 2, however, the linear perspective theory incorrectly predicts that both lines will appear identical (since, given the perspectival depth cues, they appear equidistant in depth), while the PTP approach incorrectly predicts that the line on the right will appear longer (since it is closer to the putative FoE). The tilt constancy theory, by contrast, correctly predicts that the line on the left will appear longer. Last, in Condition 3, the linear perspective theory incorrectly predicts that the line segment on the right will appear longer (since it now appears to be more distant in depth), as does the PTP approach (since it is again closer to the putative FoE). The tilt constancy theory, by contrast, correctly predicts that the lines will appear identical in length. In contrast with the tilt constancy theory, then the PTP approach predicts the wrong result in two out of the three stimulus conditions.

(6C) ''A region of the visual field containing lower angular distances from the vanishing point of converging lines tends to undergo in the next moment a greater decrease in luminance contrast.'' According to the authors, evidence for 6C comes from a supposedly new illusion in which a gray square near the center of radial display on a white background appears lighter (see the figure on p. 479). A far more straightforward explanation, however, would advert to the high density of the radiating black lines near the center of the display. Since the overall lightness of the background in the relevant region of the display is darker than in more eccentric regions, the effect here seems well predicted by traditional contrast mechanisms. I should note, in support of this alternative explanation, that a gray square when presented against a horizontal or vertical black-and-white grating of a similar density also appears lighter than when presented against a white background.

4. Conclusion

Changizi et al. (2008) emphasize that, in their view, the putative systematization of illusions is a ''more fundamental and important result'' (p. 460) than the theoretical claim that predicting the present, that is, the latency correction hypothesis, explains that result. They also point out that the putative systematization does not presuppose the empirical validity of the latency correction hypothesis. The converse, however, is not the case. The latency correction hypothesis *does* predict that visual illusions can be unified by regularities 1A–7D.

Showing, as I have done above, that the proposed classification of illusions is implausible (or untenable) in a variety of cases thus provides motivation for questioning the empirical validity of the latency correction hypothesis as well.

I should mention, in closing, that the PTP approach is partly motivated by the assumption that a VPL of 100 ms (or more) poses serious challenges to object-directed, visuomotor control during locomotion. Changizi et al. (2008) write: ''consider reaching out to grab a 1-m distant object translating in front of an observer at 1 m/s; if an observer did not have perceptual compensation mechanisms, then by the time he perceives the object, the object will be roughly 6° displaced from its perceived position, making it nearly impossible to plan and execute appropriate behavioral reaching for a catch…. In short, we should expect that visual systems have been selected to 'perceive the present,' rather than to perceive the recent past'' (p. 460). It is not clearly evident, however, that in order to *act* in the present it is necessary consciously to *perceive* the present. As Nijhawan (2008) emphasizes, ''sensory-motor processes are certainly capable of compensating for all the delays in the sensorimotor loop, including those incurred by visual processes per se'' (p. 184). This point aside, there is also a wealth of evidence that rapid and accurate visuomotor planning is possible without the involvement of processing pathways devoted to conscious vision (Jacob & Jeannerod, 2003; Koch, 2004; Milner & Goodale, 1995/2006). Moving observers, in short, may adaptively cope with approaching objects even though they do not consciously perceive them at the time action is initiated. Last, there is neuropsychological evidence that the representation of a target's direction of movement in visual area MT lags behind the stimulus by approximately 45 ms (Krekelberg, 2008). Since neural activity in MT is reliably correlated with perceived motion, even when motion is illusory (Krekelberg, Dannenberg, Hoffmann, Bremmer, & Ross, 2003; Krekelberg, van Wezel, & Albright, 2006; Schlack & Albright, 2007), this suggests that ''while we may act in the present, we perceive the past'' (Krekelberg, 2008, p. 209).[11]

Notes

1. For an attempt at classification that accords with the fox's assumptions, see Gregory (1997, 2005). Gregory proposes that illusions can be classified along two main dimensions of variation, ''appearance'' and ''cause.'' Classification along the first dimension depends on whether an illusion is characterized by what he terms *ambiguity*, *distortion*, *paradox*, or *fiction*. Classification along the second dimension depends on whether an illusion has a *physical* etiology, for example, a disturbance at the optical level, or a *cognitive* etiology, for example, a misapplication of a general rule of visual information processing. The main point is that even when a visual illusion has been classified using Gregory's taxonomy, there is still room for significant variation at the level of underlying mechanism.
2. Correctly estimating the length of the VPL in human subjects is of clear importance, since the longer the latency, the greater the perceptual compensation that should be required—and, hence, the greater the magnitude of predicted illusory effects when

perceiving the present (PTP) is inappropriate. Changizi et al. (2008) assume that the VPL is 100 ms, while Changizi (2001) assumes a much shorter VPL of 50 ms. Recent neuropsychological evidence, however, suggests that recurrent processing occurring at latencies significantly greater than 100 ms may often be necessary for conscious visual awareness (Fahrenfort, Scholte, & Lamme, 2008; Lamme, 2003, 2006). There is also evidence, notably, that certain illusions of *angular size* may depend on feedback of 3-D, contextual information from higher-level visual areas to V1 (Fang, Boyaci, Kersten, & Murray, 2008; Murray, Boyaci, & Kersten, 2006). There is a question, then, given what is possibly a much longer VPL, whether the magnitude of illusory effects predicted by the PTP approach is commensurate with the magnitude of illusory effects actually observed for relevant stimuli.

3. The goal of systematic classification in any domain of inquiry is to achieve an ordering of things into kinds (and subkinds) that facilitates new explanations, predictions, comparisons, and theories. While it seems fair to say that vision science has historically had more success in discovering visual illusions than in organizing them in a theoretically productive manner, I should emphasize that nothing I say here should be taken to invite general skepticism about efforts in this direction.
4. Nor will Correlate 7.
5. Hence, the question arises why, if the PTP theory is correct, illusions are not rife in ordinary visual experience.
6. The exception, Roberts et al. (2005) observe, is at shorter distances (<3.5 deg), where smaller inducers and complete annuli resulted in an overestimation of the target’s size.
7. Gogel and McNulty (1983) also suggest that increasing reference mark density increases the apparent *distance* between reference points. In consequence, moving stimuli are perceived to travel a greater distance over more densely referenced areas and, hence, to be traveling faster.
8. One surprising example of this effect is that moving one’s arm backwards and forwards in the dark can influence the vergence angle of the eyes and thereby dramatically modulate the size of an afterimage of one’s unseen hand (Mon-Williams, Tresilian, Plooy, Wann, & Broerse, 1997).
9. Nijhawan (1991), I should mention, provides compelling evidence that common causal mechanisms underlie both the classical 2-D and 3-D versions of the illusion. This means that it is not open to proponents of the PTP approach to claim that PTP is an adequate theory of the classical, 2-D version of the illusion. The *same* illusion plausibly arises in both the 2-D and 3-D case.
10. The latency correction approach suggests that the classical geometrical illusions have a common etiology. Prinzmetal et al. (2001), however, provide reasons to think that the underlying mechanisms of the Müller–Lyer and the Ponzo illusion are unrelated. First, the angle between the components differently affects the two illusions. While the strength of the effect in the Müller-Lyer illusion tends to increase monotonically as the angle between components becomes more acute, the strength of the effect in the Ponzo illusion first increases, then decreases as the angle between components

becomes more acute (Coren & Girgus, 1978; Fisher, 1968b, 1973). Second, Prinzmetal and Beck (2001) found that tilting observers increased the Ponzo (as well as the Zöllner and Poggendorff) illusion, but did not affect the Müller-Lyer illusion.

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