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Ecological warnings

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ABSTRACT

Our visual system has evolved over hundreds of millions of years, and is finely honed for processing natural scenes. It is reasonable to expect that warning signs that can more closely mimic ancestrally alerting stimuli (or "supernormal" versions of such stimuli) in nature would be among the most effective even today. Here we investigate warning symbols from an ecological standpoint, specifically in light of recent research in three areas of vision: color perception, the evolution of writing and typography, and visual illusions. We discuss how the color and geometry of an angry face, for example, may underly the superiority of red color and V shapes in warnings. We also describe simple heuristic ecology-based rules for the design of text in warning signs. Finally, we take up how radial line stimuli and the illusory effects they induce can be harnessed for capturing the attention of an observer, orienting him toward a warning symbol, and deterring him from moving closer.

1. Introduction

A hundred years of visual psychophysics has led to troves of facts about perception, much of it unassimilated. For example, color perception is filled with thousands of pages of arcane details about what we see as a function of a million experimental modulations. And visual illusions are collected like butterflies—named, pinned and filed away into hundreds of museum drawers. Making sense of these piles of facts requires understanding what vision is for, and this necessitates addressing the intimate relationship between an animal and the environment in which it evolved. Such an ethological or naturalistic approach to visual perception may not only give us a better grasp of the design and function of vision, but also lead to better designs for visual displays for human observers, warning displays in particular. Here we describe some implications for the design of warning signs from three such naturalistic research directions by the first author: color (and face) perception (Section 2), the evolution and perception of writing (Section 3), and visual illusions (Section 4). In some cases the research we describe helps to explain why safety science researchers have found certain stimuli to be more effective, and in other cases the research may motivate new kinds of stimuli for safety-related symbols.

2. Faces: color and shape

At first glance, pictograms would appear to be a promising means by which to convey warning messages in a language-independent manner. However, anyone who has played the game Pictionary (basically, a game of charades via doodles on paper) knows how poor we are at inferring meanings from pictograms (Davies et al., 1998)...even when we share the same culture (and household!). When we are from different cultures the difficulties for pictograms are compounded; e.g., a skull and crossbones does not universally evoke caution (Casey, 1993; Wogalter et al., 2006).

Pictograms are likely to be most effective when they tap into evolutionarily ancient mechanisms we are all born with. Images of skulls and crossbones probably played little or no role in the selection pressures shaping us, but a face with an expression of disgust like the green cartoon face of "Mr. Yuk" certainly did (albeit an exaggerated stimulus, see also Leonard et al., 1999). Facial expressions are universal across humans (Darwin, 1899; Ekman and Friesen, 2003), and symbols tapping into the key visual features of facial expressions will acquire a universal meaning. Furthermore, facial expressions have the advantage of having meanings that are emotional, *and* the advantage that facial expressions are highly effective at eliciting emotions in the observer. In addition, a face tends to attract an observer's gaze, enhancing the probability that the observer will see the warning in the first place. It is for these reasons that Mr. Yuk is such an effective warning symbol for poisons.

In particular, Mr. Yuk possesses two modalities of visual information that help it convey its message, one via its green color, and the other via the geometrical shape of its facial features. More generally, facial expressions often have a color and geometrical shape, and it may be that the fundamental evolutionary source of the emotional associations of colors and shapes is the face.

Our faces, and those of primates, have long been observed to undergo color modulations (Darwin, 1899; Hingston, 1933; Wickler, 1967), including blushing with embarrassment, reddening

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with anger, blanching with fear, and becoming sickly green. In fact, recent research has provided evidence that our trichromatic color vision (shared by many other primates) evolved in order to sense these and other skin color signals (Changizi et al., 2006a; Changizi, 2009). First, the research has shown that our cone sensitivities are in fact optimal for sensing oxygenation modulations of hemoglobin, which is the mechanism underlying our skin's ability to redden. Dichromat mammals cannot see these oxygenation-related red/green-axis color signals, nor can other vertebrates with color vision such as fish, birds and reptiles (which have *four* cones, but without the wavelength sensitivities needed to sense oxygenation modulations). Second, the new research demonstrated that the primates with color vision are exactly the ones with bare faces (and often other bare spots like the rump)—even among the prosimians which are usually furry-faced and lack color vision, the two species that *do* have color vision also stand out in having bare faces.

Color vision, then, appears to be an intrinsically socio-emotional perception, which helps to explain why colors have such strong emotional associations (e.g., Osgood, 1960; D'Andrade and Egan, 1974), and why colors are used as they are among human visual signs. Colors are often liberally employed in cartoons, such as in Disney cartoons where even the furry animals can blush. Colors are also used on cartoon faces called "smileys," used for helping to express emotions on the web. Fig. 1a shows the color of these "smileys" when sad, sick and angry, and one can see that, relative to the distribution of colors for happy faces, sad faces tend to be blue, sick faces tend to be green, and red faces tend to be angry. Colors have also long been found to be useful for enhancing visual displays (Christ, 1975). Red, in particular, has long been known to have associations with strength, anger and aggression (Osgood, 1960), and has been identified to be the most alerting color for warning signs (Wogalter et al., 1998, Leonard et al., 1999). This makes good sense given that angry faces in fact *do* tend to be red, and an angry person looking at you is an evolutionarily ancient—and contemporary—cause for alarm. In light of the color-vision-is-for-seeing-skin hypothesis, red's association with strength is connected to the fact that red cannot be signaled without sufficiently oxygenated blood in the capillaries in the skin. A person who is weak and whose arterial oxygenation is low will be unable to fake a red signal, and so red skin signals are *honest* signals of strength. This may underly why atheletes wearing red have been found to have a statistical advantage against opponents (Hill and Barton, 2005; Attrill et al., 2008). ("No matter how much I try, my opponent appears unfazed!").

Although red is the most alerting color, yellow is the next most (Chapanis, 1994; Braun and Silver, 1995; Wogalter et al., 1998), and perhaps it is the color expression of *fear* that underlies this. Whereas hemoglobin oxygenation modulations underly red/green color changes, it is the *volume* of hemoglobin in the skin that modulates skin color along a blue/yellow axis, with more blood being bluer (and darker), and less blood in the skin being yellower (and lighter). Fear, and terror, causes the blood to be kept away from the extremities, and blood volume consequently lowers in the capillaries of skin, and so skin appears yellow and light. Although a fearful person is less dangerous than an angry person gazing at you, the *cause* of fear in another may signal a danger for you as well, and that is why seeing expressions of fear—or just its color—can elicit caution in an observer. Green may be intrinsically less alerting than red because, whereas a red face likely signals anger and imminent danger, a green face may instead signal sickliness and physical disgust in the expressor—not a physical threat.

Facial expressions are not achieved just by color modulations, of course, but by muscular changes on the face, leading to characteristic geometrical shape changes in the mouth, eyes, eyebrows, and wrinkles (Ekman and Friesen, 2003). As the cartoon face in Fig. 1b illustrates, angry faces are not just red, but, even more obviously, possess certain signature geometrical features such as angular eyebrows making a "V" (e.g., Ekman et al., 2002; Lee et al., 2006), or the shape of an "upside-down" triangle as shown. Aronoff et al. (1988) found that angry masks from many different cultures (e.g., America, Ceylon, China, Dan-Guere, Japan, Java, Kwakiutl and Senoufo) possess such "V" features, and it has even been shown that "V" shapes by themselves (i.e., not on a face) generally are deemed more threatening by observers (Aronoff et al., 1988; Aronoff, 2006) and are more effective at capturing attention (Larson et al., 2007). Safety science researchers had noticed this before these latter studies, at least as far back as Riley et al. (1982) who showed that an inverted triangle shape was preferred most highly as a warning symbol. For the purposes of this paper we (in a Cognitive Science of Art course led by the first author) collected symbol data from Liungman (2004). Our data indicate that "V" shaped symbols tend to be more "cautionary" than non-"V" shaped symbols, and that inverted-"V" shaped symbols come in between, as shown in Fig. 1c.

The intrinsic warning advantages to red colors and V shapes may, then, ultimately have their foundation in our evolutionary ecology, and the face in particular. Angry faces display more oxygenated blood in the skin, and our primate color vision has evolved to be able to sense this spectral change, and to perceive it as red. And angry faces have eyebrows that become "V"-like in shape, providing a strong geometrical cue to anger. These fundamental ecological meanings appear to have found their way into the design of safety symbols, and into the visual signs of culture more generally, where red colors and "V"-shapes are often employed for symbols with aggressive or cautionary connotations.

3. Natural scenes and good typography

After a warning symbol has attracted an observer's attention—e.g., by its color or shape—it is often helpful to have brief text describing the nature of the danger or the recommended behavior. The choice of typography of warning displays is thus potentially important for ensuring easy readability. There has accordingly been efforts to gauge which fonts are most effective (e.g., Frascara, 2006). Our eyes and visual systems evolved to be competent at processing objects in natural scenes, and one might *a priori* expect that fonts and letters will be easier to see to the extent that they are more similar to the kinds of contour combinations found in natural scenes. One might even wonder whether culture could have, over time, selected for letter shapes that matched those in nature—typography matched to the topography. Recent evidence by the first author has provided evidence that this is indeed the case (Changizi and Shimojo, 2005; Changizi et al., 2006b; Changizi, 2009), and by comprehending nature's shapes one can better appreciate the shapes our visual systems "like," and potentially be better guided in the design of warning symbols.

Because the geometrical shapes of letters vary considerably across fonts (and across individuals), but do not typically much change in their topology (see Fig. 2a), a topological notion of shape is the apt one for studying letter shape. It is also apt because the geometrical shape of a conglomeration of contours in a scene changes with the observer's viewpoint whereas the topological shape will be highly robust to viewpoint modulations. Fig. 2b shows three simple kinds of topological shape, or configuration: L, T and X. Each stands for an infinite class of geometrical shapes having the same topology. Two smoothly curved contours make an L if they meet at their tips, a T if one's tip meets anywhere along the other (except at the tip), and an X if both contours cross each other. Whereas Ls and Ts commonly occur in the world—as corners and at partial occlusion boundaries as displayed in Fig. 2b—Xs do

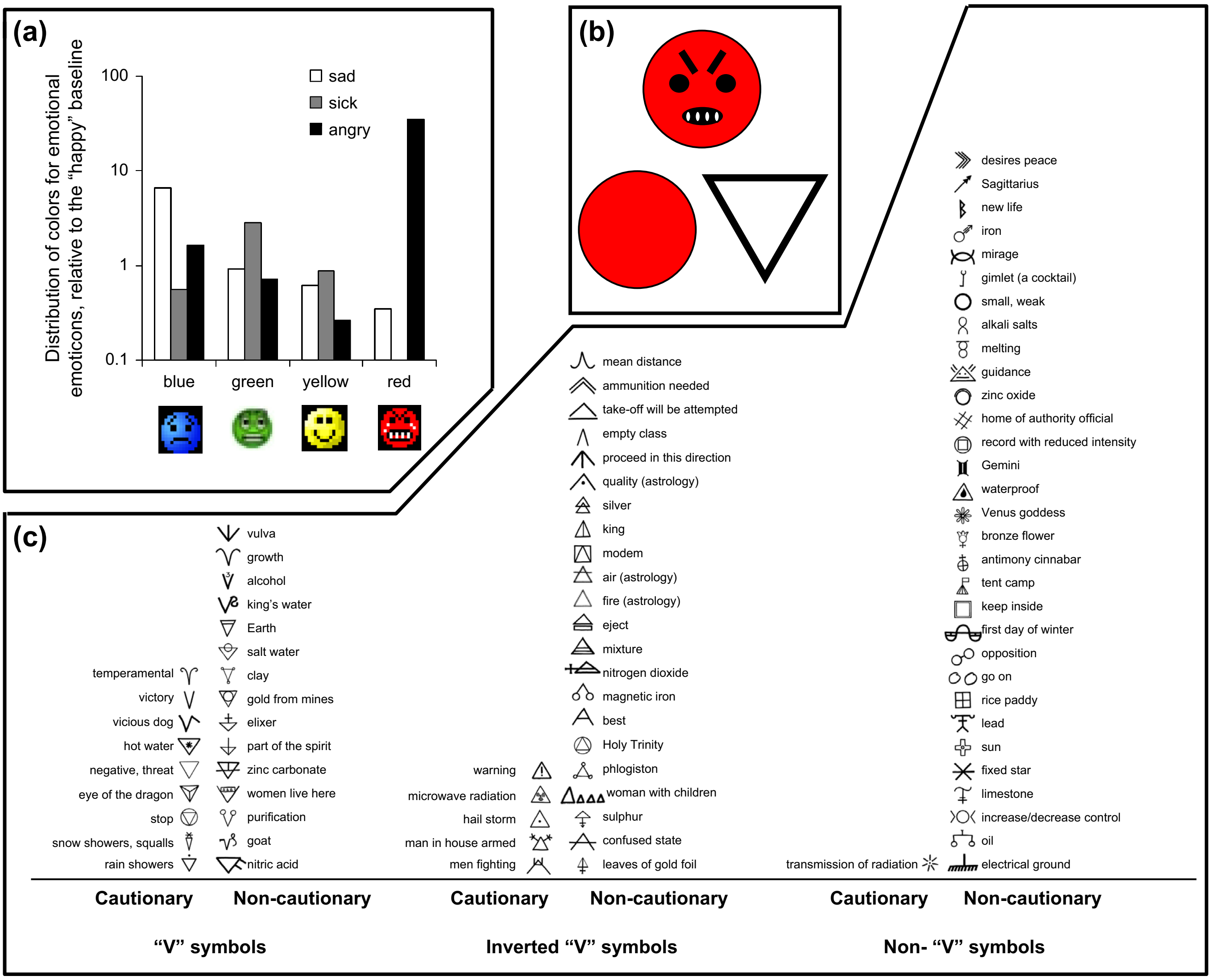

Fig. 1. Evidence that color and shape features on human facial expressions may drive the cultural evolution of the features used in emotional visual symbols. In particular, the effectiveness of red and "V" shapes for warnings may be due to the fact that these occur on angry faces. (a) Evidence that cartoon drawings of sad faces tend to be bluer, sick faces greener, and angry faces redder. Distribution of colors used in emotional (sad, sick and angry) emoticons (or "smileys") on the web (used in forums), relative to their distribution across happy smileys. For example, the data point for blue-and-sad in the plot is near 10, which means that sad faces are 10 times more likely to be blue than are happy faces. Data are from two companies: allemoticons.com (the face colors were obtained from 90 happy faces, 83 sad faces, 85 angry faces, and 29 sick faces) and smileycentral.com (the face colors were measured from 42 happy faces, 22 sad faces, 25 angry faces, and no sick faces). (b) The word "danger" on this warning sign would clearly be redundant because the face (both the color and expression) says it all. Two characteristic features of a real angry face are its reddish color and its "V" shape due to the eyebrows, summarized here as the red circle and the "V"-like triangle. Just as color has long been know to have aggressive associations (Osgood, 1960), researchers have found that a "V" shape (or the "upside-down" triangle) is associated with anger (Aronoff et al., 1988, 1992; Aronoff, 2006; Larson et al., 2007; see also Lee et al., 2006), and has long been noticed to be the most effective simple shape for warning (Riley et al., 1982). (c) Evidence that human visual symbols with cautionary meanings may have been selected for "V"-like shapes. In comparison to random visual signs without a "V" shape (right side), visual signs with a "V" shape have a tendency to be cautionary in some way (left side of plot). Visual signs with an upside-down "V" shape are intermediate, although not significantly lower than for "V" shapes. The data here are acquired from Liungman (2004), and short meanings of the symbols are given (although many have multiple meanings). The "V" and inverted-"V" cases have accumulated all the symbols in that citation having these overall shapes; the non-"V" category utilized the "get random symbol" feature at the book's web site "www.symbols.com". (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

not. And, indeed, Ls and Ts are common, but Xs rare, over the history of human visual signs and nearly a hundred writing systems (see the red squares in Fig. 2e). Fig. 2c shows four configuration types that are similar in that they each have three contours and two T junctions. Despite these similarities, they are not all the same when it comes to how commonly they can be found in nature. While three of them can be caused by partial occlusions and are thus fairly common, one of them cannot, and is thus rare in nature. Their commonness over the history of writing also shares this asymmetry, the rare-in-nature configuration also rarely occurring among human visual signs (see the green diamonds in Fig. 2e). Finally, Fig. 2d shows five configurations having three strokes that all meet at a single point, or junction, and one can see that some of these require greater coincidental alignments in the world for them to occur, and are accordingly expected to be rarer in nature. And measurements show that writing over history mimics this relative frequency distribution (see the blue circles in Fig. 2e).

Commonness in the world drives commonness in writing, something that can be seen more generally by the entirety of the data plotted in Fig. 2e (from Changizi et al., 2006b). More generally, culture appears to have over centuries selected for written words that look object-like (Changizi et al., 2006b; Changizi, 2009),

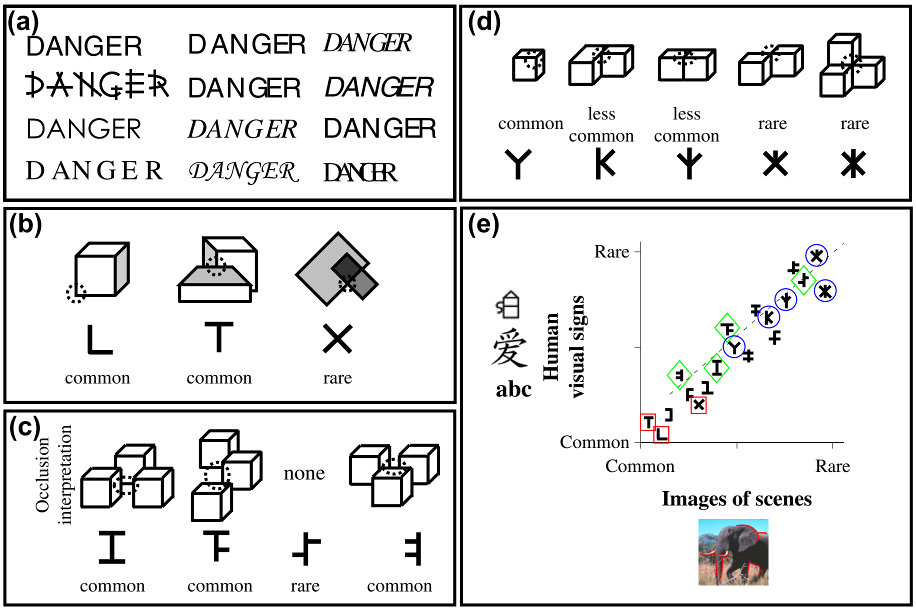

Fig. 2. Illustration that the shapes of letters throughout history tend to be driven by the shapes found in nature: culture has selected for shapes our visual systems are good at processing, and it is natural scene contour conglomerations that our visual systems evolved to be competent at processing. (a) Despite considerable shape variability among fonts, it is revealing to note how little the topology of the letters changes. Only the second occurrence of "danger" on the left is not a real font, having its L and T junctions replaced by X junctions. Despite the overall geometrical similarity of this occurrence to the others, the change in junction type makes a large qualitative difference in its appearance. This is one justification for treating shape at the topological level (see Changizi et al., 2006b for other arguments). (b) There are three topologically distinct contour-configurations with two contours, L, T, and X. Each of these junctions stands for an infinite class of geometrical instantiations (e.g., both "L" and "V" are L junctions; "T" and "J" are T-junctions; "X" and "+" are X-junctions). In natural images, L and T junctions are common, resulting primarily from corners and partial occlusion, respectively, as the figure illustrates. X junctions, on the other hand, are rare, and do not occur among opaque objects in an environment. They can occur, for example, if a partially transparent surface is in front of a contour, as shown; but this is rare in the natural world compared to corners (Ls) and partial occlusion (Ts). X junctions are also rare among human visual signs (see part (e) of this figure). (c) The four topological configurations have three strokes and consist of two T junctions. Because T junctions are typically due to partial occlusion, the main natural source of such an image would be partial occlusion, and a partial occlusion interpretation for three of these is shown. For one of these, however, there is no possible scene with opaque objects behind objects such that that configuration would result, and it is accordingly rare in the world. We will therefore expect that it is rare compared to the other three among letters and other human visual signs, because our brain mechanisms are less competent at processing it. (d) The five single junction three-stroke topological configurations, along with a sample block world scene that could lead to it. Moving from "Y" rightward, more and more coincidences in the world are required to result in the configuration, meaning the configurations roughly become increasingly rare. (e) Plot of the rank order–most common to least common–of configuration types among human visual signs versus rank order among natural images (from Changizi et al., 2006b). These are highly correlated, suggesting that the more common configurations in the world tend to be, the more common they are among human visual signs. The shapes around the configurations help to illuminate the configurations discussed in (b) red squares, (c) green triangles and (d) blue circles. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

thereby harnessing the natural powers of our visual system (Changizi et al., 2006b; Changizi, 2009), allowing us to read with remarkable efficiency. In order for words to be object-like, letters must be object-junction-like. And, in fact, letters from over 100 writing systems over history have approximately three strokes per letter, independent of the number of letters in the writing system, and thus letters are the *size*, in number of strokes, of object junctions (Changizi and Shimojo, 2005). And, as we saw just above, letters also have the topological shapes found in nature (Changizi et al., 2006b). Note that the shapes found in "nature" are principally due to the fundamental, invariant, contour-conglomerations occurring among three dimensional environments with opaque objects strewn about. It does not depend on anything peculiar about our ancestral habitat (see Changizi et al., 2006b; Changizi, 2009).

In regard to the design of warning signs, the research referred to above suggests that culture has *already* honed the shapes of writing for the eye, similar to how culture has, over time, figured out the "meaning" of red colors and "V" shapes as discussed earlier. However, cultural selection is blunt: although one finds broad patterns across culture reflective of cultural selection for letters shaped like nature (or angry symbols disproportionately colored red and shaped like a "V"), culture allows large variability around the optimal design for the eye and brain. Finding the broad pattern across culture allows one to distill the fundamental principles that have been bluntly selected for, and explicitly design more efficient letters and fonts. In particular, the horizontal axis in Fig. 2e provides a simple prescription for warnings: all things equal, choose configurations farther to the left in that plot.

4. Optic flow and perceptually-dynamic static stimuli

Although it is reasonable to suspect that emotional stimuli like angry faces (as discussed in Section 2) may serve best to elicit aversive behavior in human observers, there are other kinds of stimuli that naturally tend to orient an observer in a manner that may be appropriate for warnings. One important kind concerns optic flow. When you move forward, the visual stimuli in your environment flow radially away from a point out in front of you called the focus of expansion. The focus of expansion provides crucial visual information to the observer concerning his heading—it typically *is* his heading—and observers have a tendency to fixate toward it, something aiding in the control of locomotion (Wilkie and Wann, 2003; Wann and Swapp, 2000).

Because of temporal limits in retinal integration, real optic flow can cause streaks on the retina, and forward motion results in optic streaks emanating radially from the focus of expansion. Research by the first author has provided evidence that the static converging lines found in classical geometrical illusions are interpreted by our visual system as optic streaks, and that the visual system is "under the impression" that the observer is moving forward toward the presumed focus of expansion, i.e., heading toward the vanishing point of the converging lines (Changizi, 2001, 2003, 2009; Changizi and Widders, 2002; Changizi et al., 2008). The visual system possesses mechanisms that attempt to overcome the significant delays (about a tenth of a second) between the time light hits the retina and the time a perception is subsequently elicited (e.g., see a review in Nijhawan (2008)), and when moving forward the resultant perception needs to accord with how the optic flow will have expanded about 100 ms after the retinal stimulation.

One consequence is that regions of the visual field near the focus of expansion—or near the vanishing point of converging lines—are perceptually expanded (in anticipation of their actual growth in visual angle in the next moment, were the observer moving forward). When the stimulus is in fact a static radial display merely mimicking optic streaks around a focus of expansion, the result will be an illusory expansion that does not match reality. These ideas have not only helped explain classical geometrical illusions like those in Fig. 3a (Changizi, 2001, 2003; Changizi and Widders, 2002), but have also led to a general unified theory of hundreds of illusions over history (Changizi et al., 2008; Changizi, 2009).

The radial display stimuli underlying many of these illusions are potentially promising for enhancing warning signs. First, because, as mentioned, radial displays like in Fig. 3a naturally tend to coax an observer to fixate toward it, a warning sign possessing a radial display is more likely to be observed. And, second, because such stimuli perceptually amplify the region near the vanishing point (like the amplification of the grid region in Fig. 3a), warning symbols or text placed there will be easier to see.

There are, in addition, a variety of illusions that appear to be due to similar perceptual mechanisms, and which may have certain advantages for warning signs. For example, Fig. 3b shows an illusion called the Bulging Grid by Foster and Altschuler (2001), which bulges if you loom toward it. Placing the text "STAY BACK" on such a grid may be quite effective, for if the text does not suffice, perhaps the fact that the wall appears to be "reaching out to punch you" may make the point. Fig. 3c is called the Widders Fuzzy Balls Illusion (Changizi, 2009), where short quick looms toward the center create the impression that the balls are flowing outward faster than they should. This has advantages for warning symbols because, when scaled up to a size relevant for a warning display, even a small observer movement toward it creates a perceptually strong illusion (because, again, the illusion needs only very short looms), hopefully enhancing the likelihood that the observer pays attention to any warning sign placed there. Fig. 3d shows an instance of the Widders Ball Illusion (Changizi, 2009), where looming toward the center creates the perception that the red color in the center flows outward, filling up the ball with red. Looming away, on the other hand, leads to the red contracting toward the center. One can also create red–green versions of this, so that the ball becomes red as you approach it (helping accentuate a "keep away" message), and becomes green as you recede away from it (now giving the message that your current behavior is safe). A striking illusion due to Pinna and Brelstaff (2000) is shown in Fig. 3e, this one leading to the perception of rotation as you move toward or away from the center. Such a remarkable effect could hardly fail to capture an observer's attention, thereby enhancing the chance that they will see any warning message at the center. These illusions just mentioned rely upon forward motion, but the one in Fig. 3f does not require motion at all. It is a variant of an

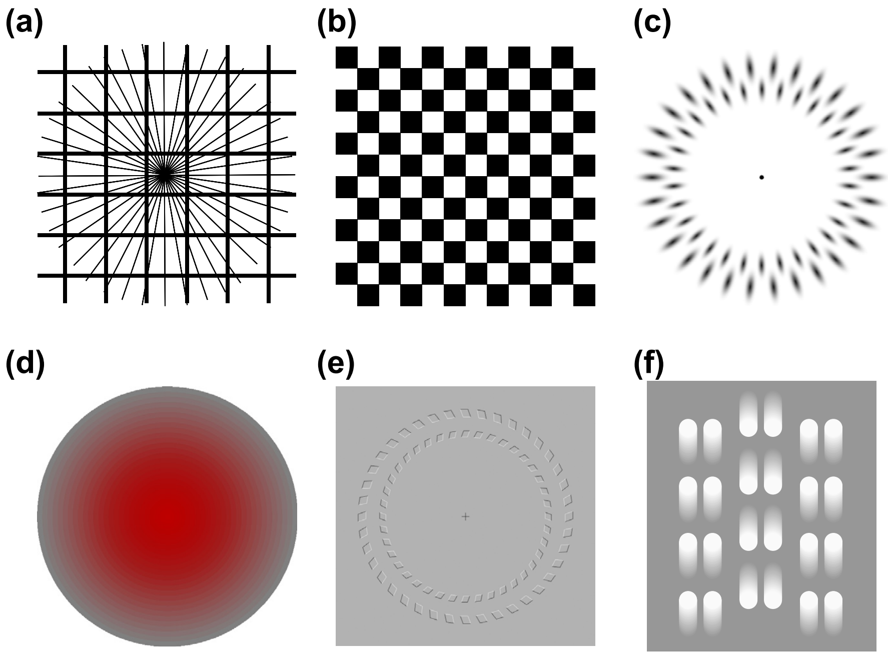

Fig. 3. Illustration of several illusions related to observer motion, all which have potential design advantages as warning symbols. (a) A classical geometrical illusion related to the Hering/Ehrenstein illusion (Ehrenstein, 1925; Orbison, 1939). The radial lines serve to perceptually expand the visual field region near the vanishing point, which can help accentuate a warning symbol. Also, there is evidence that the visual system treats these radial lines as if they are optic smear due to forward motion (Changizi, 2001, 2003, 2009; Changizi and Widders, 2002; Changizi et al., 2008), in which case radial lines may help orient eye fixations toward the vanishing point (at which a warning message is placed) because forward-moving observers tend to fixate on the direction they are headed in (Wilkie and Wann, 2003; Wann and Swapp, 2000). (b) The "Bulging Grid" illusion (Foster and Altschuler, 2001). When an observer fixates on a checker square and looms toward it, the grid appears to bulge outward toward the observer. See Changizi et al. (2008) for its relationship to the illusion in (a). (c) In the Widders Fuzzy Blob Illusion, short quick looms toward the center lead to the impression that the blobs are flowing outward faster than they should, something potentially of use for warning symbols since it may help to initially attract a person's attention to a warning message. (d) The Widders Ball Illusion, wherein looming toward the center creates the impression that the inner color spreads outward to fill the ball (and looming away does the opposite). In this instance, red is in the center, and so movement toward the stimulus leads to a greater negative warning (i.e., filled with red). (e) An illusion by Pinna and Brelstaff (2000) in which movement toward the center leads to the perception of rotating circles. (f) An illusion related to Akiyoshi Kitaoka's "Hearts and tears," this one not requiring any observer movement. Just looking at the figure creates the perception of motion, likely attracting an observer's attention, which can then be directed to a warning symbol. Kitaoka has other well-known illusions such as "Rotation Snakes" (not shown here), which could also serve an important role in warning design. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

illusion invented by Akiyoshi Kitaoka, and one perceives vertical motion (center column moving downward, side columns moving upward), as if the tear drops or blurs are moving on the page. Such a creepy perceptual "crawling" of the surface is potentially strongly orienting for observers, at least encouraging them to stop and take notice.

5. Discussion

Our intent here has been to bring greater attention to ecological (with a lower-case 'e', as opposed to Gibsonian "direct perception" approaches) and evolutionary approaches in vision, with the hope that by better understanding the fundamental evolutionary underpinnings of visual stimuli, one can design warning stimuli even more effective at communicating safety information and eliciting appropriate behavioral responses in observers. The approaches addressed here emanate from fundamental ecological invariants, not – as is often the (unfair) caricature of evolutionary psychology – hypothesized peculiar features of an ancestral environment. In particular, the three sections here concerned visual characteristics of human faces, natural scenes (filled with opaque objects strewn about), and optic flow during forward movement. Although we have concentrated entirely on visual stimuli, an appreciation of the ecological and evolutionary foundation of any of our sensory modalities will aid in the construction of more effective warnings (see an examination of the ecological auditory foundations of speech in music in Changizi, 2011).

The illusions we saw in Fig. 3b–f, despite being static figures and thus candidates for a warning sign, lead to dynamical perceptions–perceptions of movement—in many cases contingent on the direction of motion of the observer. Such stimuli open up the possibility for warning symbols that "turn on" only when needed – e.g., a ball that turns strongly red only when an observer approaches a dangerous device – *without* the need for any technology (Wogalter and Mayhorn, 2006), screen, or electricity. Although relying on unrelated perceptual mechanisms, Schyns and Oliva (1999) have devised faces that only appear angry when the observer is at a certain distance from the image, allowing for signs that suddenly become angry and alerting when an observer gets too close. Also in the context of static stimuli which perceptually change dynamically depending on the context are skin-toned colored tabs placed on skin (Changizi and Rio, 2009): such tabs initially appear invisible on skin, but become strongly colored as the skin color changes (for clinical reasons, say). For example, if the skin becomes slightly shifted toward green, such a tab will suddenly appear to the eye (due to color contrast) as colored red, thereby warning that arterial deoxygenation may have occurred.

Fig. 4 helps pictorially summarize the three ecological threads we have discussed. The first ecological topic concerned the stimuli associated with emotional faces (Section 2, and Fig. 1), and the face in Fig. 4 has both angry features we discussed, its red color and V shape (as well as other features we did not take up, such as bared teeth). The second ecological idea concerned the typography that may be best for warning symbols (Section 3, and Fig. 2), and the conclusion there was that visually effective text tends to look like nature, something culture has seen to it to give us—something upon which our powerful ability to read rests. This is illustrated in Fig. 4 by the sample text there, already optimized fairly well (by cultural selection over time) for the eye. And, finally, Fig. 4 shows a radial display (Section 4, and Fig. 3), which is a cue that the observer is moving toward the face, which helps capture attention, pull fixations toward the face, and even amplify the perceived visual image.

Although the symbol in Fig. 4 is meant only as a summary device, and has not been subjected to psychophysical comparisons to other stimuli, it is clearly an emotionally evocative and cautionary stimulus, and our hope is that this work will, more generally, motivate novel ecologically-motivated visual stimuli for warning signs. The empirical work behind the strands of research reviewed here concern testing the "meaning" of these stimuli to the brain, and although these approaches serve as rich springs for ideas for warning signs, experimental work must in each case be done in the context of their efficacy as warning signs.

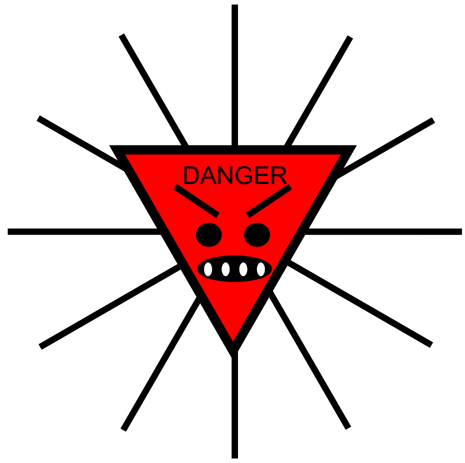

Fig. 4. An illustrative warning symbol that possesses features from the three topics covered in this paper: (i) red and "V" on faces, (ii) letters that look like nature (which reflects cultural selection), and (iii) optic streaks from forward motion. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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