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Stain on texture: Perception of a dark spot having a blurred edge on textured backgrounds

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ABSTRACT

When distinguishing illumination from reflectance edges, both edge blurriness and textural continuity across an edge are generally used as cues to promote the illumination-edge interpretation. However, when these cues were combined, i.e., when a dark spot having a blurred edge was placed on textured backgrounds, we unexpectedly found that the spot appears stained or painted rather than differently illuminated ("stain on texture" phenomenon). This phenomenon suggests a disruptive interaction between the visual processing of blurred edges and background texture. Our experiments showed that middle spatial-frequency components of background texture play a critical role in producing this interaction. Specifically, when a textured background had relatively stronger energy in middle spatial-frequency bands, the dark spot having a blurred edge on the textured background was perceived as differing in reflectance. The findings are discussed in view of multiple levels of visual processes: one mainly concerns low-level features such as spatial-frequency components and another is a higher-level process that takes into account the likelihood of spatial configurations in natural scenes, such as "spot shadow" in which the shadow is isolated and the shadow caster is out of sight.

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1. Introduction

The interpretation of retinal image intensity is inherently ambiguous because an infinite number of combinations of illuminance and surface reflectance can produce the same retinal image intensity. To resolve this ambiguity, the visual system analyzes and interprets the information about luminance edges, including cues for distinguishing illumination from reflectance edges.

Several cues for luminance-edge classification have been indicated in previous studies (reviewed by Gilchrist, 2006; Kingdom, 2008). One important cue is edge blurriness (Fig. 1a) (Adelson, 1995; Agostini & Galmonte, 2002; Elder et al., 2004; Hering, 1874/1964; Hillis & Brainard, 2007; Land & McCann, 1971). In natural lighting conditions other than point light sources, an edge of a shadow tends to be blurred because the edge of a shadow caster obstructs only some of the light from the illuminant. Traditionally, Hering (1874/1964) demonstrated that covering a blurred edge of a shadow, called a "penumbra," with a black sharp band makes the shadowed region appear as a reflectance change. He thus suggested that edge blurriness could be a cue for interpreting the edge as an illumination edge. In addition, it has been shown that the illumination-edge interpretation promoted by edge blurriness could, in turn, change lightness perception (Adelson, 1995; Agostini & Galmonte, 2002; Hillis & Brainard, 2007) and three-dimensional shape perception (Elder et al., 2004).

Another cue is textural continuity across a luminance edge (textural continuity in short, hereafter) (Fig. 1b) (Anderson, Singh, & Meng, 2006; Lotto & Purves, 2001; Schofield et al., 2006; Schofield et al., 2010). As an illumination change projected on a textured background multiplicatively affects retinal image intensity in general, the spatial pattern of the texture remains consistent across the illumination edge. Some studies have shown that the textural continuity could promote the illumination-edge interpretation (Anderson et al., 2006; Schofield et al., 2006, 2010) and thereby change lightness perception (Lotto & Purves, 2001). In addition to edge blurriness and textural continuity, consistency of color (Kingdom, 2003, 2008), depth (Gilchrist, 1977; Gilchrist, 1980) or motion (Kersten et al., 1996; Knill Kersten, & Mamassian, 1996, chap. 6; Weiss, 2001) across a luminance edge

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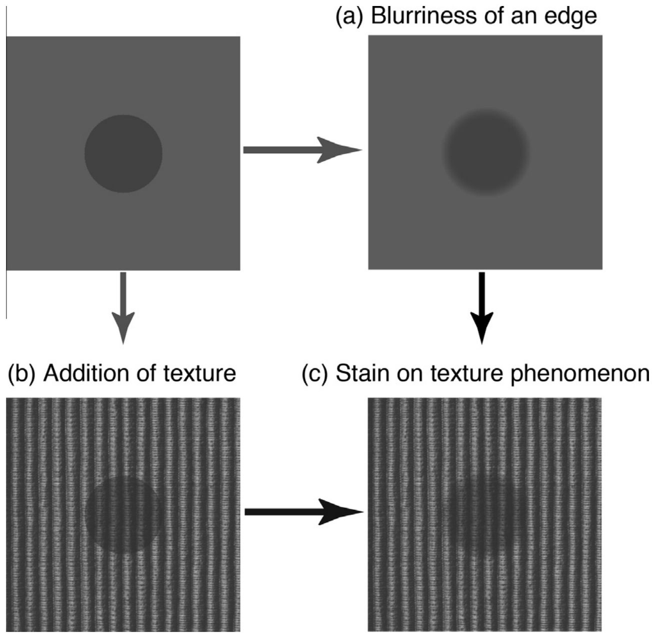

Fig. 1. Edge classification cues and stain-on-texture phenomenon. (a) Edge blurriness and (b) textural continuity across an edge are used as cues for interpreting the edge as an illumination edge. However, (c) the combination of the two cues, i.e., the dark spot having a blurred edge on the textured background is interpreted as differing in reflectance like a stain would.

has also been demonstrated as a cue for the illumination-edge interpretation.

In natural viewing conditions, these multiple cues coexist in a visual image, and thus integrating information across the multiple cues would be crucial for improving the luminance-edge classification. To better understand this integration of multiple cues, we started to investigate the combined effects of edge blurriness and textural continuity and found a new phenomenon, which we call "stain on texture": when we combined the two cues and placed a dark spot having a blurred edge on textured backgrounds (Fig. 1c), the spot appeared stained or painted rather than differently illuminated. We had expected that combining the two cues would make the illumination-edge interpretation more robust, because either cue promotes the illumination-edge interpretation. However, an opposite effect was observed, which suggests a disruptive interaction between the visual processing of edge blurriness and background texture.

To elucidate the nature of the interaction and the combined effects of edge blurriness and textural continuity in general, the present study explored the factors that could produce the stain-on-texture phenomenon. As edge blurriness poses difficulties in directly modulating textural continuity across the edge, e.g., modulating the phase of textural components across the edge, the type of texture was varied to investigate the interaction between edge blurriness and textural continuity. The popular checker-shadow illusion (Adelson, 1995) and related studies (Agostini & Galmonte, 2002; Hillis & Brainard, 2007) suggest that the stain-on-texture phenomenon would not be observable on all types of textured backgrounds. This is because in the checker-shadow illusion, a dark blurred region placed on a coarse-checker background is perceived as a shadow, and thus a gray patch in the shadowed region appears lighter because the shadow component is discounted. This observation implies that specific combinations of textured backgrounds and blurred edges would be critical for producing the stain-on-texture phenomenon. Thus, we first investigated the phenomenon using several different types of textured backgrounds.

2. Experiment 1

In the first experiment, we quantified the stain-on-texture phenomenon using uniform and three textured backgrounds.

2.1. Methods

2.1.1. Observers

Seven observers, who were naïve to the purpose of the experiment and had normal or corrected to normal visual acuity, participated in Experiment 1.

2.1.2. Apparatus

The stimuli were generated using Matlab 7.1 in conjunction with the Psychophysics Toolbox 3 (Brainard, 1997; Pelli, 1997). They were displayed on an accurately calibrated 22-inch TOTOKU color monitor (CV921X) driven by an NVIDIA video card with a pixel resolution of 1280×1024 and a frame rate of 100 Hz. The intensity of each phosphor could be varied with 10-bit resolution. A chin/forehead rest was used to maintain a viewing distance of 57 cm. The experiment was run in a dark room.

2.1.3. Stimuli and procedure

Four types of backgrounds of $12° \times 12°$ were used: "fabric," "marble," coarse-checker, and uniform backgrounds (Fig. 2a). A dark circular region (4° in diameter), which simulated a cast shadow in terms of luminance contrast, was placed at the center of the background. The fabric and the marble background were taken from the McGill Calibrated Colour Image Database (http://tabby.vision.mcgill.ca; Olmos & Kingdom, 2004), and the original images were converted to gray scale. Although the materials of these backgrounds were not explicitly indicated in the database, we named them "fabric" and "marble" backgrounds on the basis of their appearances. The spatial-frequency composition of these backgrounds is shown in Fig. 4. We first found the stain-on-texture phenomenon with the fabric background and thus selected it for investigation. As the fabric background had the anisotropic orientation distribution, the marble background having a nearly isotropic one was also selected. The coarse-checker background was chosen to reproduce a situation similar to the checker-shadow illusion (Adelson, 1995). The check size was 3 deg (check frequency was 0.17 c/deg). The mean luminance of each background was 9 cd/m^2. RMS contrasts of fabric, marble, and checker backgrounds were 0.86, 0.59, and 0.77, respectively. The uniform background consisted of a plain field of 9 cd/m^2.

The edge of a dark center region was either sharp or blurred. Under the sharp-edge condition, the luminance of the center region was multiplicatively reduced to 40%. Under the blurred-edge condition, the edge of the center region was blurred by a cosine window with the blur width of 20′ or 40′. The size of the dark spot was fixed to 4° in diameter in this study, because we preliminarily confirmed that the spot size did not matter much if we used a circular isolated spot.

The rating tasks involved illumination and reflectance judgments. In the illumination judgment, observers rated to what extent they felt the center region on a background had resulted from a change in illumination (e.g., a shadow) or transparency (e.g., a dark filter) on a five-point scale[1]. In the reflectance judgment, they rated to what extent they felt the center region had resulted from a change in reflectance (e.g. a stain or paint) on a five-point scale. A rating of 5 on the scale meant that the center region definitely appeared differently illuminated (or stained); a rat-

[1] In this and other experiments (Experiments 2, 3, & 5), the perception of a shadow and that of a dark filter were not differentiated in the illumination judgment. However, they were separately rated in Experiment 4.

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