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On the number of perceivable blur levels in naturalistic images

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ABSTRACT

Blur is a useful cue for depth. Natural images contain objects at a range of depths whose depth can be signaled by their perceived blur. Here, to evaluate the usefulness of blur as a depth cue, we estimate the number blur levels that observers can perceive simultaneously. To estimate this value, observers discriminated and classified dead leaves patterns that contained a controlled distribution of blur levels but are more complex or naturalistic than stimuli typically used in blur research. We used a 2-IFC discrimination task, in which observers reported the interval that contained more blur levels and a classification task, in which observers reported the number of perceived blur levels. In both tasks, observers could not discriminate or classify more than four levels of blur in the stimulus reliably. In isolation from other cues, blur may provide only a coarse cue to depth and add limited depth information when present in natural scenes with complex distributions of blur and multiple depth cues.

1. Introduction

Blur is often present during the viewing of scenes. Image blur has the drawback in that it can affect perceived image quality (Ahumada, 1993), but it has been used artistically by photographers (Massey & Bender, 1996) in tilt-shift photography to delight viewers. In biological optical systems, blur places a fundamental limit on the information that can be transmitted (Banks, Geisler, & Bennett, 1987). Retinal blur drives accommodation (Ciuffreda, 1991; Ciuffreda et al., 1990; Fisher and Ciuffreda, 1988) and has been implicated in eye growth and the development of myopia and hyperopia (Hodos and Kuenzel, 1984; Walker et al., 1978).

Blur has the ability to signal the range of depths present in a natural image (Fisher & Ciuffreda, 1988) and presenting images at a single focal plane may be the reason why 3D displays look flatter than one would expect (Watt, Akeley, Ernst, & Banks, 2005). Recently, (Maiello, Chessa, Solari, & Bex, 2014) examined fusion and vergence in stereoscopic images of natural scenes captured with a plenoptic camera. The addition of gaze-contingent dioptric blur, proportional to the real depths of objects in scenes, reduced the time to fusion and vergence instability. Burge and Geisler (2011) showed that defocus blur is a useful depth cue, but their stimuli contained only one level of blur (i.e., there was no variation in depth within their images) which is generally not true of natural scenes. A question that remains unanswered is how useful blur is for signaling depth when processing complex scenes that contain multiple levels of depth or blur. At least three factors each place constraints on the utility of blur as a depth cue, how finely blur can be discriminated, the number of discrete blur levels that can be perceived simultaneously, and the ability of blur to signal the sign (whether an object is blurred because it is front/behind the point of interest).

Observers can discriminate small changes in image blur (Murray & Bex, 2010; Mather & Smith, 2002; Wang & Ciuffreda, 2005; Watson & Ahumada, 2011) which indicates that blur discrimination between two levels of blur is unlikely to be a major constraint for blur as a depth cue. The second factor, the number of discrete blurs levels that can be encoded and signaled simultaneously by the visual system, has yet to be investigated and addressing this question is the chief aim of this paper. Natural scenes typically contain objects at a range of depths which results in variation in blur across the retina. The ability of the visual system to use the variation in blur as a cue to the multiple depth planes depends on the number of depths that the visual system can signal simultaneously in a glance. Finally, it is not clear whether the sign of depth can be signaled by blur. There is some evidence (Nguyen, Howard, & Allison, 2005) that the blur from chromatic aberration can be used to determine the sign of blur, but whether other blur cues (e.g., high-order monochromatic aberration) can signal the sign of depth from blur is unknown.

Although the functional impact of blur is usually assessed with visual acuity, the influence that blur has on image quality is

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ultimately evaluated by observers when viewing natural scenes which are much richer stimuli than the edges and letters typically used to study perceived blur. The use of natural images to study perceived blur has been complicated by the lack of a single standard computational approach to estimate perceived image blur from image statistics; several methods that can estimate local blur have been described (see Elder, 1999; Marziliano et al., 2002; Taylor and Bex, submitted for publication; Vu et al., 2012; Wang and Simoncelli, 2003 for examples) but no single method has been adopted as a standard. Given the lack of a standard method for measuring and manipulating local blur in natural sciences, we adopted a simpler and more controllable stimulus that captures some of the characteristics of natural scenes as a compromise. We used naturalistic 'dead leaves' stimuli (see Fig. 1) that contains the range of contrast values present in natural scenes, edges at a variety of orientations, occlusions, and a variety of blur levels. The use of these stimuli allows us to investigate local perceived blur as a depth cue in a highly controlled way. However, this method does introduce some limitations including the difference between Gaussian versus dioptric blur, the identity between near and far blur and a failure to match blur to an individuals optics, which may have been learned by the observer (Nguyen et al., 2005).

The work in this paper was inspired by the literature on transparency perception for motion and depth stimuli. Several researchers have measured how many stimulus levels can be simultaneously perceived for moving dot patterns (see Edwards & Greenwood, 2005; Edwards & Rideaux, 2012; Mulligan, 1992) and depth images defined by stereoscopic disparity (Akerstrom & Todd, 1988; Gepshtein & Cooperman, 1998; McKee & Verghese,

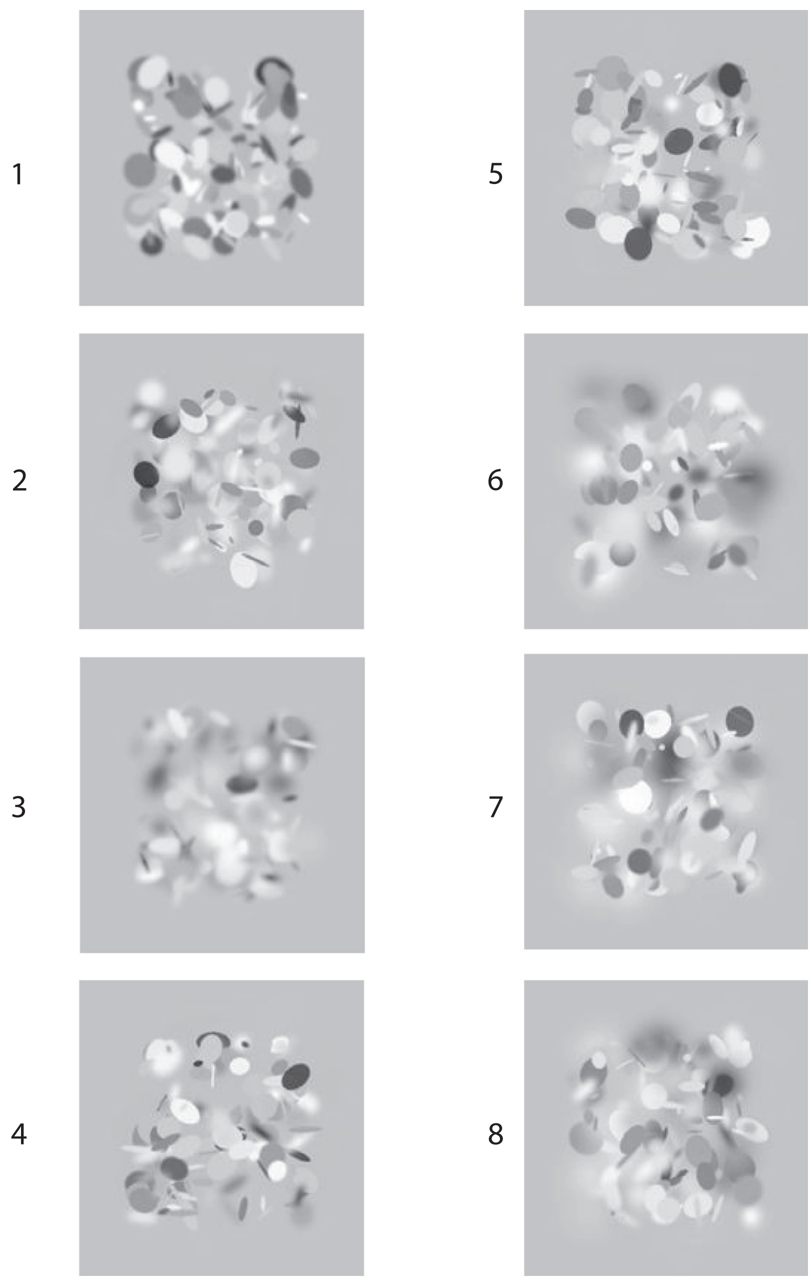

Fig. 1. Examples of the dead-leaves patterns used in Experiments 1 and 2. Each image shows a dead leaves patch that contains a number of blur levels. The first column shows dead leaves patches with one through four blur levels, and the second column the dead leaves patches with five through eight blur levels.