Vision Research 82 (2013) 13–21

Contents lists available at SciVerse ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

Generalization of cue recruitment to non-moving stimuli: Location and surface-texture contingent biases for 3-D shape perception

Anshul Jain *, Benjamin T. Backus

Graduate Center for Vision Research, SUNY College of Optometry, 33 W. 42nd Street, New York, NY 10036, USA
SUNY Eye Institute, 550 Harrison Street, Suite 340, Syracuse, NY 1320, USA

ARTICLE INFO

Article history:
Received 31 July 2012
Received in revised form 23 January 2013
Available online 22 February 2013

Keywords:
Cue recruitment
Perceptual learning
Perceptual bias
3D shape
Bistable perception

ABSTRACT

Long-lasting perceptual biases can be acquired through training in cue recruitment experiments (e.g. Backus, 2011; Haijiang et al., 2006). Stimuli in previous studies contained motion, so the learning could be explained as an idiosyncrasy in some specific neuronal population such as the middle temporal (MT) area (Harrison & Backus, 2010a). The current study addresses the generality of cue recruitment by testing whether motion is necessary for learning a cue-contingent perceptual bias. We tested whether location and a novel cue, surface texture, would be recruited as cues to disambiguate perceptually bistable stationary 3-D shapes. In Experiment 1, stereo and luminance cues were used to disambiguate shape according to location in the visual field, and observers' ($N = 10$) percepts on ambiguous test trials became biased in favor of the contingency during training. This bias lasted into the following day. This result together with previous studies that used moving stimuli suggests that location-contingent biases are easily learned by the visual system. In Experiment 2, location was fixed, and instead the new cue to be recruited was a surface texture. Learning did not occur when stimuli were para-foveal, texture was task-irrelevant, and disparity was continuously present in training stimuli ($N = 10$). However, learning did occur when stimuli were central, task was texture-relevant, and disparity was transient ($N = 8$). Thus, we show for the first time that an abstract cue, surface texture, can also be learned without motion.

1. Introduction

As an individual's environment changes over time, optimal perception would require that the individual's perceptual system adapt. Learned biases reflect this adaptation: they show what the system believes to be the most likely interpretation of the sense data (Brunswik, 1956; Helmholtz, 1910/1925). The learned biases can be described within the framework of Bayesian inference as a change in prior belief, with examples including changes in the light-from-above prior (Adams, Graf, & Ernst, 2004), the convexity prior (Champion & Adams, 2007), and the stationarity prior (Jain & Backus, 2010). Visual cues constrain perceptual interpretations, and changes in the way the visual system uses visual cues to construct perceptual appearance are an important form of adaptation. Learning a new use for a visual cue, so that it affects some attribute of appearance that it did not affect before, is called cue recruitment (Backus, 2011).

A series of cue-recruitment studies have shown that the rotation direction of a perceptually bistable 3D object can be made contingent on new signals such as its translation direction (Haijiang et al., 2006), location (Backus & Haijiang, 2007; Haijiang et al., 2006; Harrison & Backus, 2010a), or shape (Harrison & Backus, 2012). Location was also recruited as a cue upon which the stationarity prior became contingent (Jain & Backus, 2010). The apparent rotation direction of a cylinder can be made contingent on binocular vertical disparities (Di Luca, Ernst, & Backus, 2010). In these studies, all stimuli contained motion. Thus, it could be argued that motion is a critical requirement for this form of learning. Since these stimuli engaged motion sensitive areas, such as MT (Born & Bradley, 2005, review) and MST (Saito et al., 1986; Tanaka & Saito, 1989), it is therefore important to know whether cue recruitment is an idiosyncratic phenomenon within the motion perception system.

First, we examined whether motion signals are necessary for cue recruitment by measuring the strength of learned location-contingent bias using stimuli that did not contain motion (Experiment 1). Second, we tested whether a bias contingent on surface-texture can be acquired to affect appearance of a static 3D shape. The significance of an acquired texture-contingent bias is that, like motion, there could be something special about location that makes location particularly easy to learn (i.e. recruit) as a cue. This study is not the first to look at other cues besides location; other recruited cues include shape (Harrison & Backus, 2012; Sinha & Poggio, 1996), vertical disparity (Di Luca, Ernst, & Backus,

* Corresponding author at: Graduate Center for Vision Research, SUNY College of Optometry, 33W 42nd Street, New York, NY 10036, USA.
E-mail address: ajain@sunyopt.edu (A. Jain).

0042-6989/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.visres.2013.02.006

2010), translation direction (Haijiang et al., 2006), and motion within the display that is not part of the object itself (Backus, Jain, & Fuller, 2011), but all of these studies used moving objects to measure the acquired cue-contingent perceptual bias.

2. General methods

2.1. Subjects

Thirty-two observers participated in the study, twelve in Experiment 1, twelve in Experiment 2A and 8 in Experiment 2B. Data from four observers, two each in Experiment 1 and Experiment 2A were discarded because they could not perform the task reliably (i.e. their answers on Training trials did not agree with the visual cues that were intended to control appearance on those trials). All observers were naïve to the purpose of the experiments. The experiments were conducted in compliance with the standards set by the IRB at the Graduate Center for Vision Research, SUNY College of Optometry. Observers were paid for their participation. All observers had normal or corrected-to-normal vision and a stereo acuity better than 4 min of arc (TNO stereo-acuity test).

2.2. Apparatus

The experiments were implemented using the Python-based virtual reality software toolkit Vizard™ 3.11 (WorldViz LLC, Santa Barbara, CA, USA) on a Dell Precision T3400 computer running the Windows XP operating system. Stimuli were rear projected onto a 1.8 m × 2.4 m screen using a Christie Mirage S + 4k projector. The display refresh rate was fixed at 120 Hz and the screen resolution was set at 1024 × 768 pixels. Observers were seated at a distance of 1.5 m from the screen and wore red-green anaglyphs to view the stimuli.

3. Experiment 1 – location contingent bias

3.1. Stimuli

The stimuli consisted of a dihedral right angle constructed by joining two squares along one of their edges to mimic the outline of an "open book". The edges of the squares were struts (rectangular parallelepipeds). Each face of the 'book' contained 20 randomly placed dots to stabilize the percept of a rigid 3-D object. Each edge of the square was 15 cm in length before projection and the stimuli were viewed from a distance of 1.5 m thus subtending a visual angle of 5.7° when perpendicular to the line of sight. The stimuli could be perceived in one of two configurations, an open book facing towards an observer or an open book facing away from the observer (Fig. 1). On any given trial, stimuli were presented vertically centered 5.7° above or below a central fixation square.

3.2. Procedure

The experiment consisted of two types of trials: Training trials and Test trials. On training trials, the observer's percept was controlled using three cues that specified depth relations: binocular disparity, proximity-luminance covariance (Dosher, Sperling, & Wurst, 1986), and occlusion (occlusion bar as well as internal occlusions). Importantly, we put stimulus configuration (as determined by depth cues) into correlation with location. Thus, on training trials, observers were presented with the "facing away" configuration above fixation and the "facing towards" configuration below fixation, or vice versa (counter-balanced across observers). Observers pressed a key to initiate a trial. After this key-press, the stimulus was displayed for 1.15 s. After the first 0.5 s, one of the two faces within the dihedral angle stimulus (randomly chosen) was highlighted (edge thickness was increased by a factor of 1.5) for 0.25 s and then the stimulus returned to its previous state for the rest of the trial. The observer's task was to report whether the highlighted face appeared closer or farther away than the other face, which uniquely determined the perceived configuration. Because the face to be highlighted was chosen randomly, observers' responses were uncorrelated with both the perceived configuration and the stimulus location. The task was chosen to discourage observers from using cognitive strategies to make their response rather than rely on their percept. Observers were instructed to report the trial as a "missed trial" by pressing a third key if they were unsure how to respond, because either they failed to notice the probe or the stimulus or both, and were told that by being attentive they could minimize their fraction of missed trials. Observers did not receive any feedback. Fig. 2 shows typical trial sequences for two training trials and a test trial. The fixation-cross disappeared after the observer responded and it appeared again after 1 s indicating that the observer could initiate the next trial.

Perceptually bistable stimuli such as the one used in this experiment are known to switch perceptual states spontaneously (Attneave, 1971; Blake & Logothetis, 2002). Further, transients like the probe used in this experiment have shown to cause a perceptual switch (Kanai et al., 2005). To minimize this effect, which would have reduced the apparent magnitude of learning, observers were instructed to respond based on the percept at stimulus onset in case their percept switched during the trial or use the "missed trial" key if they were not sure. In post-experiment interviews observers were asked about this issue explicitly. They universally reported that there were very few instances of switching and that they felt they were able to follow the instructions to respond according to their percept at stimulus onset. Thus we do not

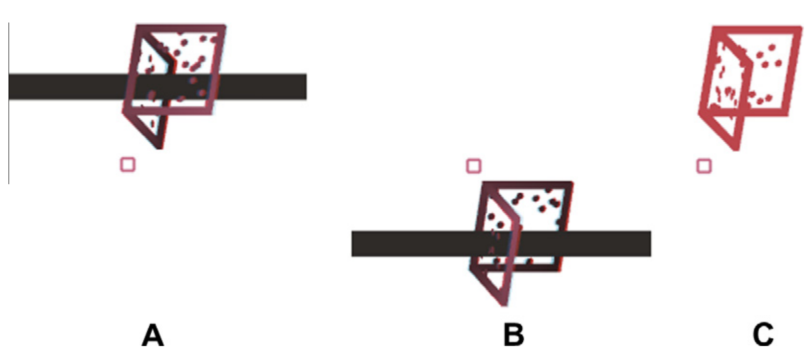

Fig. 1. Stimuli used in Experiment 1. Panels A and B depict the two configurations of the disambiguated stimuli presented on training trials. Training stimuli were presented in stereo using anaglyph glasses. Panel C shows a typical ambiguous stimulus presented on test trials. Test stimuli were presented monocularly. The white background used here is for illustration purposes only; the stimuli were presented on black background during the experiments.