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A trained perceptual bias that lasts for weeks

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ABSTRACT

Classical (Pavlovian) conditioning procedures can be used to bias the appearance of physical stimuli. Under natural conditions this form of perceptual learning could cause perception to become more accurate by changing prior belief to be in accord with what is statistically likely. However, for learning to be of functional significance, it must last until similar stimuli are encountered again. Here, we used the apparent rotation direction of a revolving wire frame (Necker) cube to test whether a learned perceptual bias is long lasting. Apparent rotation direction was trained to have a different bias at two different retinal locations by interleaving the presentation of ambiguous cubes with presentation of cubes that were disambiguated by disparity and occlusion cues. Four groups of eight subjects were subsequently tested either 1, 7, 14, or 28 days after initial training, respectively, using a counter-conditioning procedure. All four groups showed incomplete re-learning of the reversed contingency relationship during their second session. One group repeated the counter-conditioning and showed an increase in the reverse bias, showing that the first counter-conditioning session also had a long-lasting effect. The fact that the original learning was still evident four weeks after the initial training is consistent with the operation of a mechanism that ordinarily would improve the accuracy and efficiency of perception.

1. Introduction

The role played by previous experience in determining how things look has been of interest for more than 300 years (Berkeley, 1709). Documenting a change in appearance caused by learning can be difficult, however, because observers may not accurately remember how a thing looked in the past. A strategy for overcoming this difficulty is to use perceptually bistable stimuli, because once the visual system itself makes the noisy dichotomous decision, the observer can effortlessly report the result of the visual system's decision (Backus, 2009, 2011; chap. 6; Pylyshyn, 1999).

A revolving wire-frame Necker cube is such a stimulus. It is perceived at stimulus onset to be rotating in one of exactly two directions, i.e., it is perceptually bistable. Furthermore, the apparent rotation direction of the cube can be conditioned to depend on retinal location, an effect that persists for at least 24 h (Backus & Haijiang, 2007; Haijiang et al., 2006; Harrison & Backus, 2010a). Specifically, if a cube presented above fixation on "training trials" is disambiguated by depth cues so that it appears to rotate in one direction, while a cube presented below fixation on other training trials is disambiguated so that it appears to rotate in the opposite direction, then ambiguous cubes on interleaved test trials will rapidly come to have the same apparent rotation direction as was trained at their respective locations. This training occurs mostly independently at each location (Harrison & Backus, 2010a), however, the difference in bias at the two locations, measured on test trials, is a useful measure of the learning because it is robust to their common initial bias. To control for initial bias that is different across locations but common across observers—a possible if unlikely situation—the contingency between location and rotation direction is counterbalanced across observers.

Short term priming effects, that may or may not be functionally important for vision, are sufficient to explain the learning that occurs within a single session (e.g. Brascamp et al., 2008). However, these same priming effects make it impossible to quantify the strength of any long term learning, because only one ambiguous trial at the start of the second session is independent; all the rest will be influenced by the previous trials in the second session (Brascamp et al., 2009, 2008; Harrison & Backus, 2010a,b; Pastukhov & Braun, 2008; van Dam & Ernst, 2010).

Under these circumstances a useful strategy to quantify the learning is counter-conditioning: the strength of the initial learning can be assessed during the second session by measuring how resistant the system is to learning from training trial stimuli that

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rotate in the direction opposite to the training in the first session. The extent to which the perceptual outcomes for ambiguous cubes in the second session adopt the new location-rotation contingency (or alternatively, are perceived in accordance with the first session's contingency) is then a measure of the bias retained from the first session. This strategy of conditioning and then counter-conditioning has shown that learned biases last for many minutes (Backus, 2011, chap. 6) and even overnight (Haijiang et al., 2006). Here we ask whether learned biases last many days, as would presumably be the case if the learning is implemented by mechanisms that are useful for deciding the appearances of objects that are encountered repeatedly but not every day. A positive finding of persistent bias cannot prove a functional role, but failure to find it might argue against such a role.

2. Materials and methods

Most aspects of the materials and methods are as previously described (Harrison & Backus, 2010a). The methods were designed to ensure that subjects' responses reflect the visual appearance of the stimulus, rather than other factors such as a bias in post-perceptual cognitive decisions or motor choice, cognitive strategy, or fixation strategy (Backus, 2009; Backus, 2011, chap. 6; Haijiang et al., 2006). For convenience we describe the most important of these design choices again, below.

2.1. Subjects

Subjects were adults with normal or corrected-to-normal vision who were able to do the task correctly on training trials, recruited from the College of Optometry and from the New York City metropolitan area with advertisements at craigslist.com. We tested 4 groups of 8 subjects, with varying numbers of days between the first (conditioning) session and the second (counter-conditioning) session. Subjects returned for counter-conditioning on either the 2nd, 8th, 15th or 29th day. The group that received counter-conditioning on the 2nd day also received the same counter-conditioning on the 8th day, to evaluate the effect of elapsed time as compared to the effect of counter-conditioning *per se* as a factor in dissipating the bias.

2.2. Stimuli

On Session 1, all groups viewed 480 trials consisting of a 50:50 pseudorandom mixture of disambiguated and ambiguous cubes, presented by rear-projection, identical to those used previously (see Harrison & Backus, 2010a; for details). Disambiguated cubes contained binocular disparity and revolved around a central strip so as to provide an occlusion cue (Fig. 1a). Ambiguous cubes were presented monocularly, and contained no other cues to depth (Fig. 1b). Each transparent face of the cube contained 25 randomly placed dots, which stabilized the cube's appearance as a single rigid rotating body on ambiguous trials. All cubes were viewed through red–green glasses, and were presented using orthographic projection. Luminance in the red and green channels was balanced on training trials and cross-talk was minimized (Mulligan, 1986) to prevent the Pulfrich effect from determining apparent rotation direction on monocular test trials.

2.3. Task

Subjects' task was to indicate whether the transit direction of a comparison dot, which completed horizontal paths through the fixation marker, was the same as the motion of the front (near part) or back (far part) of the cube. The comparison dot is shown to the left of the fixation square in Fig. 1a. Subjects indicated "matches near" or "matches far" by pressing "2" or "8" on a numeric keypad. This task exploits a perceptual coupling (Hochberg & Peterson, 1987): on each trial, leftward or rightward transit direction was randomly chosen for the comparison dot, with equal probability, so the response mapping was randomly re-assigned on each trial. Thus subjects' responses were not correlated with the actual dependent variable of interest, namely apparent cube rotation, nor with the top vs. bottom position of the stimulus, nor with dot motion itself. This feature of the task design ensures that location-contingent motor bias cannot explain the data. The dot was presented at fixation depth on training trials and monocularly on test trials. The cube and comparison dot remained on the screen for a minimum of 1.5 s and the subject's response terminated the presentation.

2.4. Data analysis

From subjects' responses we calculated the fraction of ambiguous (test trial) cubes perceived as rotating in the same direction as the disambiguated (training trial) cubes at the top location in Session 1 (Fig. 2A–C and Fig. 3). These fractions were then transformed into z-scores, i.e. we used a probit (inverse-cumulative-normal) transformation (Backus, 2009; Dosher, Sperling, & Wurst, 1986). For each subject, z-scores at the two locations were differenced

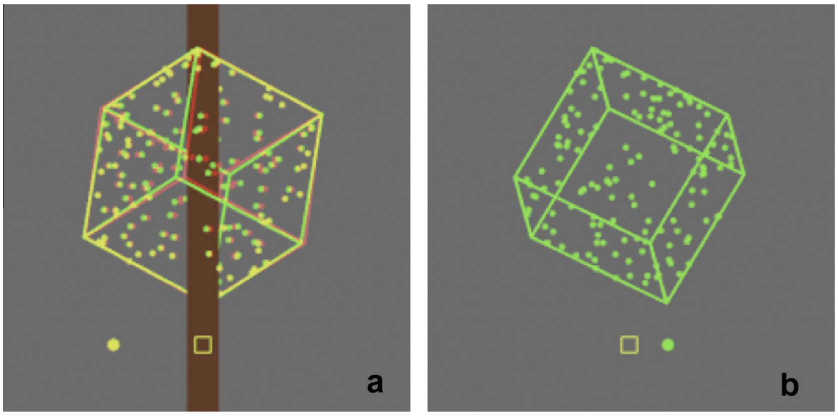

Fig. 1. Cropped screen shots showing example stimuli: (a) cube disambiguated by (geometrically correct amplitude) binocular disparity and occlusion, and (b) ambiguous cube. Both cubes are depicted here at the "top" location, centered 12° above the binocular fixation marker. Cube edges were of 20.0 cm length, hence subtended approximately 11.5° of visual angle at the viewing distance of 1 m, when in the frontoparallel plane. Width and breadth of cube edges was 0.3 cm. Width of the central occlusion strip was 4.0 cm. Cubes rotated about a vertical axis at a rate of $45^\circ\ \mathrm{s}^{-1}$, and the comparison dot (shown to the left or right of fixation) had a speed of 15.7 cm s^{-1}, similar to the horizontal image speed of the nearest (and farthest) part of the cube.