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A novel face aftereffect based on recognition contrast thresholds

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ABSTRACT

Previously, repulsive perceptual-shift face aftereffects have been reported. Here, we introduce a novel face adaptation method involving changes in contrast thresholds for face recognition. We find non-monotonic changes for adapted faces, with facilitation at short and suppression at long durations. Thresholds for unadapted faces were unaffected at short but elevated at long durations, more than those for the adapted face. A population-coding model showed that selective suppression of adapted representations cannot explain repulsive perceptual-bias aftereffects. The findings indicate greater complexity to adaptation, with facilitation, suppression, lateral inhibition of unadapted representations, and additional perceptual factors at long durations.

1. Introduction

Adaptation aftereffects are changes in perception induced by a preceding stimulus. Aftereffects are widespread in the visual system, occurring for both low-level properties such as luminance, contrast, spatial frequency, orientation, and motion (Anstis, Verstraten, & Mather, 1998; Blakemore & Campbell, 1969; Gibson & Radner, 1937), and for higher-order representations such as shapes and faces (Clifford & Rhodes, 2005; Leopold, O'Toole, Vetter, & Blanz, 2001; Suzuki, 2005). Experimentally, aftereffects are revealed by at least two phenomena (e.g., Blakemore & Nachmias, 1971). The first is a perceptual shift, usually a 'repulsive' aftereffect, in which the perception of a subsequent stimulus is shifted away from the properties of the preceding adapting stimulus. For example, in orientation, adaptation to a stimulus with counter-clockwise tilt will cause a subsequent vertical stimulus to appear tilted clockwise (Gibson & Radner, 1937). The second is a change in detection thresholds: typically, viewing the adapting stimulus causes stimuli with properties similar to the adaptor to become harder to perceive (Blakemore & Campbell, 1969; Regan & Beverley, 1985).

To explain both types of aftereffects, perceptual shifts and threshold changes, many use models in which the percept reflects the net population response of a large number of individual units, with each unit responsive to only a limited range of values of the stimulus property in question (e.g., orientation). In such models, adaptation is often explained by response suppression. That is, during sustained viewing of an adapting stimulus with a particular value for that property (e.g., 10° counter-clockwise tilt), the responses of units preferring that value are reduced, impairing the detection of subsequent stimuli with similar values, while units responding to other values (e.g., 45° clockwise tilt) are unaffected. In addition to the predictable effects on thresholds, a second result of this selective reduction in response is that the net population response for the next stimulus (e.g., vertical tilt) is shifted away from suppressed values, resulting in a 'repulsive' perceptual shift (e.g., towards clockwise tilt) (Clifford, Wenderoth, & Spehar, 2000; Coltheart, 1971; Mather, 1980).

Recently repulsive perceptual-shift aftereffects have also been demonstrated for faces. Adapting to one facial identity biases the perception of a subsequent face away from this identity (Fox, Oruc, & Barton, 2008; Leopold, O'Toole, Vetter, & Blanz, 2001). Similar aftereffects have been shown for facial properties such as expression, gender, ethnicity (Fox & Barton, 2007; Webster, Kaping, Mizokami, & Duhamel, 2004), viewpoint (Fang & He, 2005), and gaze direction (Jenkins, Beaver, & Calder, 2006). These face aftereffects are not due to aftereffects for lower-level image properties such as contrast, size, or tilt (Butler, Oruc, Fox, & Barton, 2008), as they persist despite changes in image size (Zhao & Chubb, 2001), retinal location (Fang & He, 2005; Leopold, O'Toole, Vetter, & Blanz, 2001) and viewpoint (Jiang, Blanz, & O'Toole, 2007).

Because perceptual-shift aftereffects derive from the change in the '*relative*' balance of activity in units that respond preferentially to the adapting stimuli versus those that do not, they cannot inform us of the '*absolute*' changes in the responses of these units

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induced by adaptation. If viewing of a specific face makes the observer less likely to perceive the properties of this face in a subsequent ambiguous test face, is this due to suppression of the representations of the adapting face, facilitation of the representations of unadapted faces, or both? To address this question experimentally, the second type of aftereffect – changes in luminance contrast threshold – may be useful. In this technique, the independent variable is not the amount of face A versus face B mixed in the ambiguous test stimulus, but the amount of luminance contrast, which is therefore orthogonal to the relationship between A and B.

In this study, our first goal was to use contrast thresholds for face recognition to determine how adaptation affects recognition performance. Classical models of adaptation based on selective response suppression would predict that thresholds for recognizing the adapted face should be elevated, while those for recognizing unadapted faces should not be affected (Coltheart, 1971; Graham, 1989; Mather, 1980). The contrast threshold technique provides an instrument to directly test this account.

Our second goal was to use this technique to determine the temporal dynamics of adaptation effects. Typically, lower-level aftereffects (e.g., contrast, tilt, or visual motion) grow monotonically with increasing adapting duration in the range of seconds to minutes, whether they are measured as perceptual shifts (Magnussen & Johnsen, 1986) or elevated detection thresholds (Blakemore & Campbell, 1969). Results for faces from two studies so far, both using perceptual-shift aftereffects, also show a logarithmic increase in aftereffect magnitude when adapting duration was increased from 1 s to 16 s (Leopold, Rhodes, Muller, & Jeffery, 2005; Rhodes, Jeffery, Clifford, & Leopold, 2007). However, very brief adapting durations (<500 ms) were not used, although both neurophysiological recordings (Albrecht, Geisler, Frazor, & Crane, 2002) and psychophysical studies (Suzuki, 2005) have shown substantial effects for non-face stimuli with brief adaptation, e.g., improved orientation discrimination following adaptation for periods of 400–500 ms (Dragoi, Sharma, Miller, & Sur, 2002; Muller, Metha, Krauskopf, & Lennie, 1999). Furthermore, there is growing evidence that higher-level aftereffects may emerge at shorter adapting durations (Fang, Murray, Kersten, & He, 2005; Kohn, 2007; Suzuki, 2005) than their lower-level counterparts. Thus, in the present study we measured aftereffects following adapting durations of 10–6400 ms to extend our knowledge of the temporal dynamics of face aftereffects, and to determine this for both adapted and unadapted faces.

2. Experiment 1: a contrast-based face aftereffect

2.1. Methods

2.1.1. Observers

Seven observers with normal or corrected-to-normal vision participated (2 males, ages 25–35), of which four participated in the main experiment (1 male, ages 25–32), and four participated in the control experiment (1 male, ages 28–35). With the exception of IO, who participated in both experiments, all observers were naïve to the purposes of the experiment. The protocol was approved by the review boards of the University of British Columbia and Vancouver Hospital, and informed consent was obtained in accordance with the principles in the Declaration of Helsinki.

2.1.2. Apparatus

Stimuli were displayed on a SONY Trinitron 17-inch GDM-G500 monitor at 1024 × 768 resolution and refresh rate of 100 Hz. Viewing distance was 99 cm. Cambridge Research Systems (CRS) VSG Toolbox for Matlab was used to present the stimuli via a CRS VSG 2/3 card. Displays were gamma-corrected by means of an automated calibration procedure using the VSG software and an OptiCAL photometer (Model OP200-E) by CRS. Average luminance was 40 cd/m^2.

2.1.3. Stimuli

Face stimuli were five female faces displaying a neutral expression obtained from the Karolinska Database of Emotional Faces (Lundqvist & Litton, 1998). All face images were first converted to grayscale using Adobe Photoshop CS 8.0 (www.adobe.com). The images were then manipulated using Matlab (www.mathworks.com). An oval aperture was superimposed on the face images, outside of which the display was uniform gray set at the mean luminance of 40 cd/m^2. The tip of the nose and the pupils were used as anchors to align faces horizontally and vertically. All faces had the same pose (frontal), tilt (vertical), and eye-color (brown), without obvious distinguishing marks such as moles and visible hair, to minimize discrimination based on trivial features. Luminance values inside the oval aperture were normalized such that the average was set to the mean luminance and the root-mean-squared (rms) contrast (the standard deviation of luminance values divided by mean luminance) to one. These images were the standard templates whose contrasts were later modified by the staircase procedure. The horizontal and vertical extents of the cropped faces were 5.1 × 7.2° visual angle, respectively, at the viewing distance of 99 cm.

2.1.4. Procedure

Face recognition contrast thresholds at the 82% correct level were estimated using a five-alternative forced-choice (5-AFC) paradigm. In each trial, one of the five alternative faces was selected randomly as the test stimulus and shown for 150 ms. The observer was then required to indicate which of the five faces the test stimulus resembled. A psychophysical staircase implemented in Psychophysics Toolbox (Brainard, 1997; Pelli, 1997) based on the Quest procedure (Watson & Pelli, 1983), controlled the contrast of the test face at each trial. An estimate of the threshold is obtained at the end of a fixed 40-trial run per staircase.

Each trial started with an adaptation period during which either one of the five possible faces at 60% contrast or a blank stimulus was shown. The adapting duration was fixed within a block of trials, but differed across blocks. Adapting durations used were 10 ms, 20 ms, 50 ms, 100 ms, 200 ms, 400 ms, 800 ms, 1600 ms, 3200 ms and 6400 ms. The order of blocks (i.e., adapting durations) was randomized for each subject. At each trial the adaptation period was followed by a white noise mask (50 ms), a fixation cross (150 ms), a blank screen (150 ms), a test stimulus (150 ms), a blank screen (150 ms), and finally the choices screen, which remained visible until the subject responded with a keypress (see Fig. 1). Auditory feedback indicated whether the response was correct. A new trial started as soon as the observer made their keypress. There were 30 possible adapting-test pairs (6-adapting stimuli × 5-test stimuli). A separate contrast threshold was measured for each adapting-test pair, by using 30 randomly interleaved staircases, each controlling one adapting-test pair. In addition, filler trials that contained any one of the 30 adapting-test pairs, with a test stimulus at very low contrast, were randomly interspersed throughout the block with 1/6 probability, to prevent the observer from forming strategies based on tracking the progress of the 30 experimental staircases. The responses to filler trials were discarded.

The procedure for the control experiment performed to exclude contributions from low-level retinotopic properties was identical except that the adapting face was 50% larger than the test faces (i.e., 7.7 × 10.8°), and the test faces were presented 1° left or right of central fixation, determined randomly at each trial, so that the