Research Article

FITTING THE MIND TO THE WORLD: Face Adaptation and Attractiveness Aftereffects

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Abstract—*Average faces are attractive, but what is average depends on experience. We examined the effect of brief exposure to consistent facial distortions on what looks normal (average) and what looks attractive. Adaptation to a consistent distortion shifted what looked most normal, and what looked most attractive, toward that distortion. These normality and attractiveness aftereffects occurred when the adapting and test faces differed in orientation by 90° (+45° vs. −45°), suggesting adaptation of high-level neurons whose coding is not strictly retinotopic. Our results suggest that perceptual adaptation can rapidly recalibrate people's preferences to fit the faces they see. The results also suggest that average faces are attractive because of their central location in a distribution of faces (i.e., prototypicality), rather than because of any intrinsic appeal of particular physical characteristics. Recalibration of preferences may have important consequences, given the powerful effects of perceived attractiveness on person perception, mate choice, social interactions, and social outcomes for individuals.*

Visual aftereffects are called the psychologist's microelectrode because they can reveal mechanisms underlying visual experience (Frisby, 1979). A classic aftereffect is the waterfall illusion, in which stationary objects appear to move upward after the observer views a downward-flowing waterfall. Similar aftereffects follow adaptation to many simple, low-level visual attributes—orientation, spatial frequency, contrast, size, color, texture, and simple shape (e.g., Clifford, 2002; Durgin & Proffitt, 1996; Frisby, 1979; Suzuki & Cavanagh, 1998). Functionally, adaptation calibrates neural coding mechanisms to the range of stimulus values encountered (Barlow, 1972; Clifford, Wenderoth, & Spehar, 2000; Smirnakis, Berry, Warland, Bialek, & Meister, 1997).

Recently, aftereffects have been found for complex stimuli, such as faces (Hurlbert, 2001; Kaping, Bilson, & Webster, 2002; Leopold, O'Toole, Vetter, & Blanz, 2001; MacLin & Webster, 2001; Webster & MacLin, 1999). Adaptation to systematically distorted faces makes subsequently viewed faces look distorted in the opposite direction (Webster & MacLin, 1999), adaptation to a particular identity can cause an average face to take on the "opposite" identity (Leopold et al., 2001), and adaptation to a particular expression, race, or gender can cause a previously neutral image to take on the contrasting value (happy-angry, Caucasian-Japanese, male-female; Kaping et al., 2002).

Here we consider how adaptation and aftereffects can reveal mechanisms underlying aesthetic responses to faces. The question of what makes a face attractive is currently the subject of a lively debate. What standards of beauty do people have, and what sets those standards? Traits that contribute to attractiveness include symmetry, youthfulness, sexual dimorphism, and averageness (Rhodes & Zebrowitz, 2002). Perhaps the most surprising and contentious of these is averageness. The original report that computer-averaged composites were more attractive than their component faces (Langlois & Roggman, 1990) met considerable resistance. Perhaps their appeal was due to some associated characteristic, such as smooth complexions, symmetry, or pleasant expressions (Alley & Cunningham, 1991; Pittenger, 1991; Rhodes, Sumich, & Byatt, 1999). Subsequent studies have shown that these characteristics are attractive, but that averageness remains attractive when each is controlled (Rhodes & Tremewan, 1996; Rhodes et al., 1999). Certain extremes can also be slightly more attractive than average traits (e.g., large eyes—McArthur & Berry, 1987; feminized female faces—Perrett, May, & Yoshikawa, 1994; Perrett et al., 1998; Rhodes, Hickford, & Jeffery, 2000). However, this does not alter the fact that average faces are attractive or reduce the need to understand the basis of their appeal.

The average face can be thought of as occupying a central location in a multidimensional face-space, whose dimensions correspond to the characteristics people use to mentally represent faces (Valentine, 1991).[1] The precise characteristics of the average face will, of course, depend on the population of faces that a person experiences. An average Western male face has characteristics different from those of an average Chinese male face. However, little is known about how experience shapes preferences. Perhaps early experience is heavily weighted, with a critical period for learning about faces (Le Grand, Mondloch, Maurer, & Brent, 2001; Perrett et al., 2002). Perhaps recent experience is heavily weighted, to ensure a rapid response to any changes in the population. Perhaps distinct mechanisms exist to track short-term and longer-term changes in population structure.

Here we consider perceptual adaptation as a possible mechanism for rapid updating of what looks average and what looks attractive. A few minutes of exposure to consistently distorted faces can make subsequently viewed faces appear distorted in the opposite direction, so that faces with a low level of the adapting distortion look more normal than undistorted faces (O'Leary & McMahon, 1991; Webster & MacLin, 1999). Limited experience may, therefore, suffice to renormalize face-space, shifting the average toward a consistently experienced distortion. If averageness is attractive, then there should be a corresponding shift in what looks attractive (see also MacLin & Webster, 2001). Corresponding aftereffects for normality and attractiveness would indicate that people's preferences can be rapidly calibrated to match whatever physical characteristics are typical of the population of faces that they see. Such shifts would also show that average faces are attractive be-

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1. Male and female faces differ structurally, so we assume a distinct face-space for each sex. An "average face" refers to the average for one sex.

Fig. 1. A set of test images for one face in Experiment 1. Distortion levels change in 10% steps (from −50% to +50%); the most extreme compressed (negative) distortion is on the left, the undistorted face is in the middle, and the most extreme expanded (positive) distortion is on the right.

cause of their central location in a distribution of faces (i.e., their prototypicality), rather than because of any intrinsic appeal of particular characteristics, because those characteristics would become less attractive when they became less prototypical. We sought evidence for corresponding aftereffects in the perception of normality and attractiveness in two experiments.

We were also interested in whether these aftereffects reflect adaptation of high-level neural mechanisms, which code object properties like shape or configuration independent of size and position, or whether they result solely from adaptation of low-level mechanisms, which code simple image properties like orientation, spatial frequency, and contrast in retinotopic maps. Low-level aftereffects would not be robust to variations in viewpoint that characterize everyday perception of faces. Several lines of evidence suggest that adaptation of high-level, nonretinotopic mechanisms may contribute to face aftereffects. First, face normality aftereffects show a degree of size invariance (Zhao & Chubb, 2001), and face identity aftereffects show position invariance (Leopold et al., 2001), unlike low-level aftereffects. Second, when adapting and test faces differ in orientation (45° counterclockwise vs. 45° clockwise), the axis of perceived distortion changes with the orientation of the face, implicating high-level, object-based coding mechanisms (Watson & Clifford, in press). Third, exposure to undistorted faces fails to produce an aftereffect, whereas low-level aftereffects can occur following exposure to any feature value (Webster & MacLin, 1999). In Experiment 2, we investigated whether adaptation of high-level processing mechanisms contributes to face normality and attractiveness aftereffects, by presenting adapting and test faces in different orientations (+45° vs. −45°—faces in both these orientations engage face-processing mechanisms; Murray, Yong, & Rhodes, 2000).

EXPERIMENT 1

We examined whether exposure to consistently distorted faces shifts the most attractive image toward the adapting distortion, and whether this change reflects a change in what looks normal (average). The adapting faces had central features that were either expanded from the center of the face or compressed into the center of the face (varied between participants). Perceptions of attractiveness were assessed before and after 5 min of exposure to each distortion. Test faces were taken from 10 morphed continua, each containing 11 images that varied in equal steps from the compressed adapting distortion (−50%) to the expanded adapting distortion (+50%), with the original undistorted face (0%) in the middle (see Fig. 1). The 110 images were presented singly in random order, alternating with adapting faces so that adaptation would be maintained, and rated for attractiveness. We used these ratings to test whether the most attractive distortion level shifted toward the adapting distortion. Additional participants rated how normal the images looked, before and after adaptation, so that we could determine whether the shifts in attractiveness reflected shifts in what looked normal or average.[2]

Method

Participants

Forty-eight undergraduates from the University of Western Australia participated (24 female). Half adapted to compressed and half to expanded distortions. Within each group, half rated how normal the test faces looked and half rated how attractive they looked (12 participants per condition, 6 female).

Stimuli

Twenty black-and-white, full-face photographs of young adult females with neutral expressions were used. Ten were used in the adapting phase, and 10 were used in the test phase. For each face in the adapting set, we created two distortions using the spherize distort function in Adobe Photoshop: a −50% distortion, which compressed the center of the face, producing the appearance of a face in a concave mirror, and a +50% distortion, which expanded the center of the face, producing the appearance of a face in a convex mirror (see Fig. 1). For each face in the test set, we created 11 images that varied systematically in distortion level, by setting the spherize function to the following levels: −50, −40, −30, −20, −10, 0, 10, 20, 30, 40, and 50. All images were shown in black oval masks, which hid the outer hairline, but not the inner hairline or face outline. Images measured 217 × 285 pixels, displayed at 72 pixels per inch. A full set of images for one face is shown in Figure 1.

Procedure

All participants began with a *preadaptation rating phase*, in which the 110 test faces were presented in random order and rated on attractiveness or normality (1 = *unattractive*, 9 = *attractive*; 1 = *unusual*, 9 = *normal*) using the numerical keypad. They were asked to try and use the full range of the scale. Each face was shown for 1,500 ms, followed by the appropriate rating scale. Once a rating was made, the next face was displayed.

This phase was followed by the *adaptation phase*, in which participants adapted to either positive (expanded) or negative (compressed) distortions of the 10 adapting faces, which were repeatedly displayed in random order for a total of 5 min. Faces were shown for 4 s each,

2. Judgments of averageness or normality covary with computer-imaging manipulations of averageness (Rhodes et al., 1999).

with an interstimulus interval of 200 ms. Participants were asked to pay attention to each image.

Next came the *postadaptation rating phase*, in which the 110 test images were rated for attractiveness or normality. So that adaptation would be maintained, adapting faces alternated with test faces, which were presented in a rectangular box with "rate" written at the top and bottom. The sequence was as follows: adapting face (randomly chosen) for 8 s, blank screen for 500 ms, test face (randomly chosen) for 1.5 s. As in the preadaptation phase, the appropriate rating scale was displayed after each test image and remained on the screen until a response was made. To make the pre- and postadaptation rating phases as similar as possible, we presented all faces in the "rate" box in the preadaptation phase. Participants viewed the faces from a distance of 50 cm, for a visual angle of 8.6°

Results and Discussion

Figures 2 and 3 show mean ratings of attractiveness and normality, respectively, as a function of distortion level, before and after adaptation, averaged across participants. Clearly, the most attractive and most normal-looking images shifted toward the adapting distortion. Third-order polynomials were fitted to each participant's data and used to estimate the distortion level of the most attractive and most normal faces. One attractiveness rater was excluded because of poor fits (R^2 = .19 before adapting and .39 after adapting). Otherwise, fits were good (attractiveness: mean R^2 = .83, minimum R^2 = .42; normality: mean R^2 = .88, minimum R^2 = .60).

We conducted two-way analyses of variance (ANOVAs) on the mean distortion levels of the most attractive and most normal faces. In each ANOVA, adapting condition (positive, negative) was a between-participants factor and test time (preadaptation, postadaptation) was a repeated measures factor. As expected, the most attractive face shifted toward the adapting distortion (see Fig. 4). The interaction was significant, $F(1, 21) = 144.26$, $p < .0001$, and planned comparisons showed significant shifts following adaptation to both expanded (positive) distortions, $t(21) = 8.35$, $p < .0005$ (one-tailed), and compressed (negative) distortions, $t(21) = 8.64$, $p < .0005$ (one-tailed). The most normal-

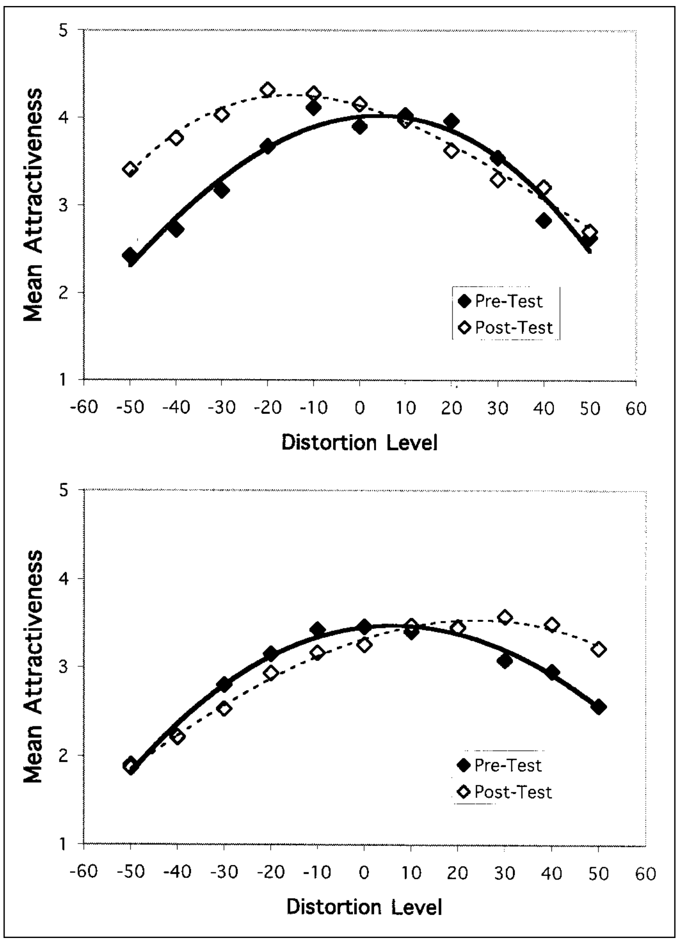

Fig. 2. Mean attractiveness as a function of distortion level, before and after adaptation to negative (compressed; top graph) and positive (expanded; bottom graph) distortions in Experiment 1. Ratings were made on a scale from 1, *unattractive*, to 9, *attractive*. Fitted third-order polynomials are shown.

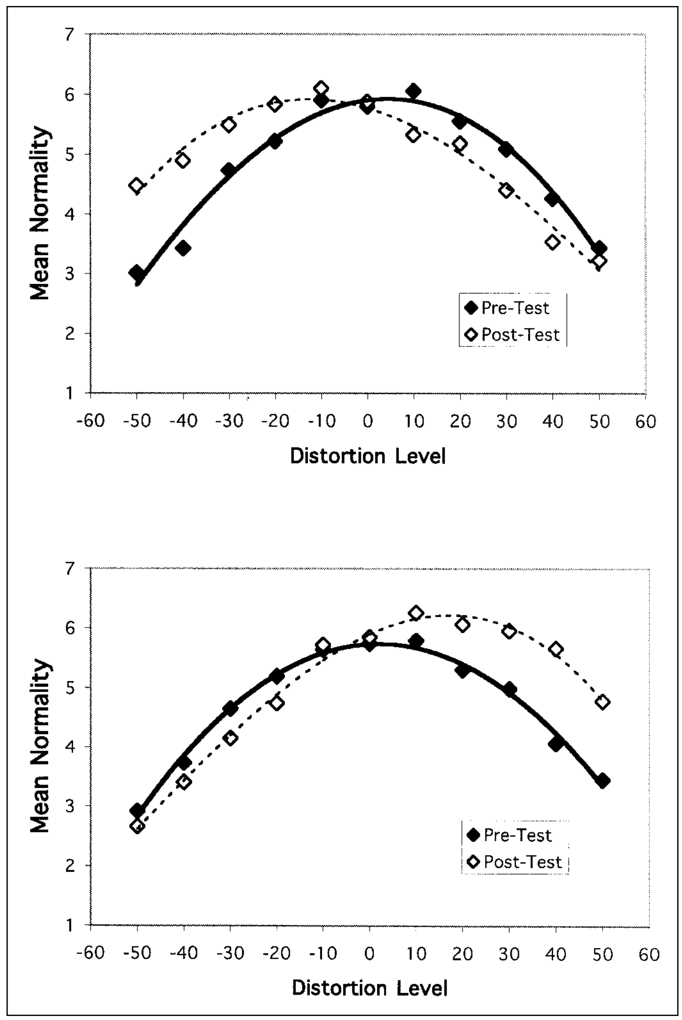

Fig. 3. Mean normality as a function of distortion level, before and after adaptation to negative (compressed; top graph) and positive (expanded; bottom graph) distortions in Experiment 1. Ratings were made on a scale from 1, *unusual*, to 9, *normal*. Fitted third-order polynomials are shown.

looking face also shifted toward the adapting distortion (see Fig. 4). The interaction was significant, $F(1, 21) = 37.24$, $p < .0001$, and planned comparisons showed significant shifts following adaptation to both expanded distortions, $t(22) = 4.55$, $p < .0005$ (one-tailed), and compressed distortions, $t(22) = 4.08$, $p < .0005$ (one-tailed).

Before adaptation, the distortion level that looked most normal was rated as most attractive, consistent with the hypothesis that averageness is attractive. After exposure to consistently distorted faces, new physical characteristics looked normal-average and were preferred. Therefore, the visual system may recalibrate rapidly in response to consistent changes in the faces people experience, so that preferences are tuned to whatever physical characteristics are prototypical.

EXPERIMENT 2

In Experiment 1, we found that exposure to systematically distorted faces produces corresponding changes in what looks average and what looks attractive. Next, we examined whether adaptation of high-level, object-based mechanisms contributes to these aftereffects. If they do, then similar effects should be observed when adapting and test faces

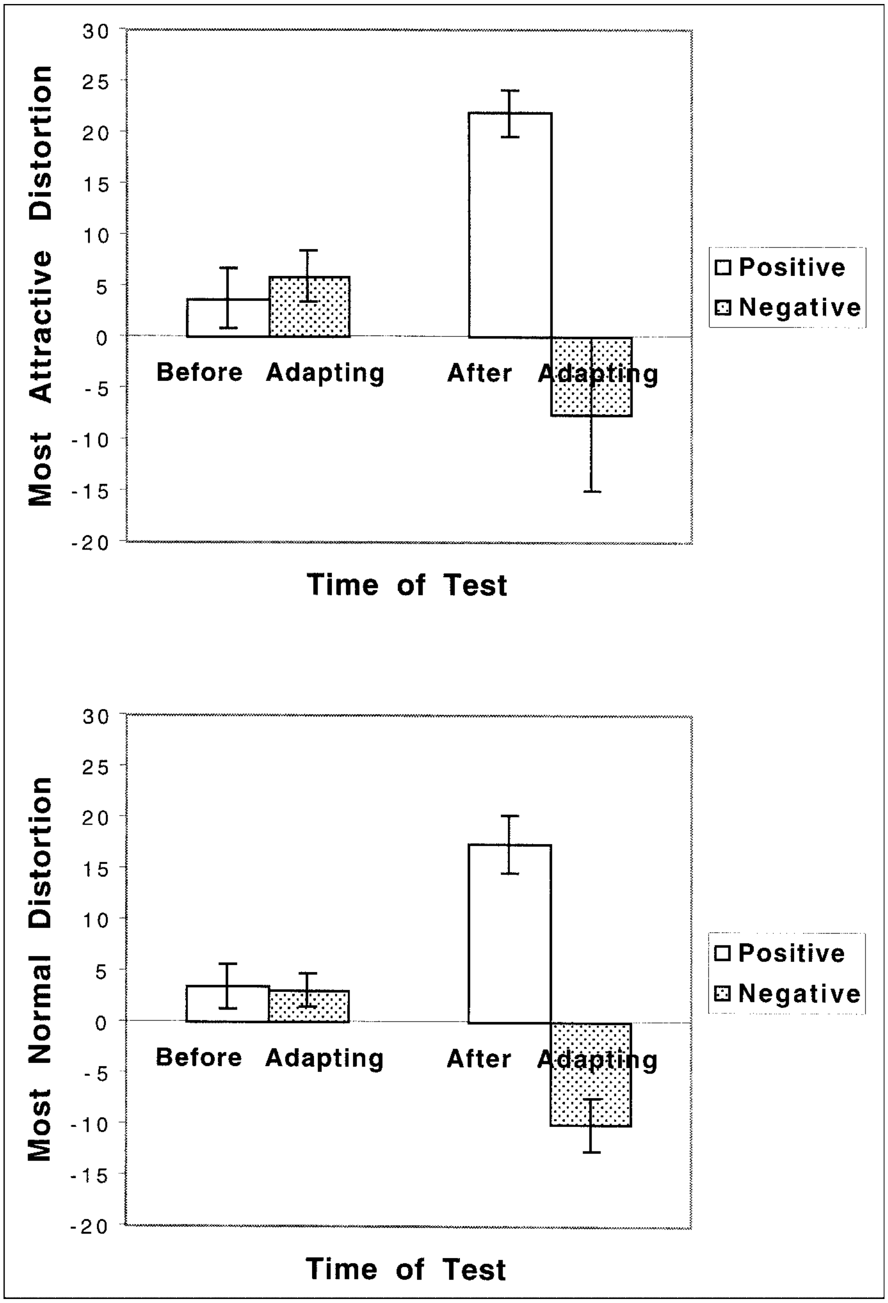

Fig. 4. Distortion chosen as most attractive (top) and most normal (bottom) before and after adapting to negative (compressed) and positive (expanded) distortions in Experiment 1.

have different orientations, with their features occupying different retinal locations. We showed adapting faces tilted 45° (clockwise or counterclockwise) and test faces tilted 45° in the opposite orientation. Faces at these orientations engage normal face-processing mechanisms (Murray et al., 2000). We used adapting distortions different from those in Experiment 1, with central features expanded or contracted horizontally rather than concentrically, to enable this manipulation and to show that the aftereffects are not limited to one kind of distortion. We expected that exposure to distorted faces would shift what looked normal and what looked attractive toward the adapting distortion despite the change in orientation.

Method

Participants

Forty undergraduates from the University of Western Australia and Macquarie University participated (28 female). Half adapted to laterally compressed distortions (14 female) and half to laterally expanded distortions. Within each group, half rated attractiveness and half rated normality.

Stimuli

The faces from Experiment 1 were used, but with a different distortion. Internal features of the adapting faces were compressed or expanded laterally (−1, +1) (see Fig. 5), by contracting or expanding along a horizontal axis relative to a midpoint on the nose. For example, for a face distorted along the horizontal axis, the pixel intensity, I_D, at location (x,y) in the distorted image is given by sampling the undistorted image, I_0, at location x', y):

$$I_D(x,y) = I_0(x',y).$$

The value of x' is given by

$$x' = round\ (x \cdot (1 - \alpha) + x_c \cdot \alpha),$$

Fig. 5. Example of the adapting distortions used in Experiment 2. Adapting faces were tilted 45° (clockwise or counterclockwise), and test faces were tilted in the opposite direction.

where x_C is the midpoint of the distortion and the function *round* denotes rounding to the nearest integer. The value of α is given by

$$\alpha = D \cdot \exp\left(-\left(\frac{(x - x_C^2) + (y - y_C^2)}{2\sigma^2}\right)\right),$$

where D controls the magnitude of the distortion and σ determines its spatial extent. Positive values of D correspond to widening the central region of the face, negative values to narrowing it. When D is zero, the image remains undistorted. A circular Gaussian envelope (σ = 30 pixels) limited the spatial extent of the distortion so that the outline of the head did not change. For each face in the test set, we created 11 images, varying systematically in distortion level across the range from +1 to −1 in steps of 0.2. The images were the same size as in Experiment 1.

Procedure

The procedure was the same as in Experiment 1, except for changes to shorten testing time. The exposure duration of adapting faces was reduced to 2 s, and the adaptation period was reduced to 1 min. During adaptation, images were selected randomly (with replacement) from the 10 adapting faces at the relevant distortion level. Two random orders were used. Duration of test faces was reduced to 1 s, and duration of alternating adapting faces was reduced to 6 s. Participants were instructed not to tilt their heads during adaptation, and were observed to ensure compliance.

Results and Discussion

Figures 6 and 7 show mean ratings of attractiveness and normality, respectively, as a function of distortion level, before and after adaptation, averaged across participants. Clearly, the most normal and most attractive images both shifted toward the adapting distortion, as in Experiment 1. Third-order polynomials were fitted to each participant's data and used to estimate the distortion level of the most attractive or most normal face, as appropriate. Fits were good (attractiveness: mean R^2 = .89, minimum R^2 = .80; normality: mean R^2 = .91, minimum R^2 = .53).

We conducted two-way ANOVAs on the mean distortion levels of the most attractive and most normal faces. In each case, adapting condition (negative, positive) was a between-participants factor and test time (preadaptation, postadaptation) was a repeated measures factor. As expected, the most attractive face shifted toward the adapting distortion (see Fig. 8). The interaction between adapting condition and test time was significant, $F(1, 18) = 39.20$, $p < .0001$, and planned comparisons showed significant shifts following adaptation to both negative distortions, $t(18) = 2.83$, $p < .01$ (one-tailed), and positive distortions, $t(18) = 6.36$, $p < .0005$ (one-tailed). The most normal looking face also shifted toward the adapting distortion (see Fig. 8). The interaction was significant, $F(1, 18) = 58.22$, $p < .0001$, and planned comparisons showed significant shifts following adaptation to both negative distortions, $t(18) = 5.16$, $p < .0005$ (one-tailed), and positive distortions, $t(18) = 5.27$, $p < .0005$ (one-tailed).

Initially, the optimally attractive distortion differed slightly from the most normal-looking distortion (see Fig. 8). Nevertheless, adaptation produced corresponding shifts in attractiveness and normality, as in Experiment 1. The reduction of adaptation from 5 min to 1 min had little effect on the aftereffects. This shows how quickly preferences can be recalibrated by experience. The aftereffects survived changes in

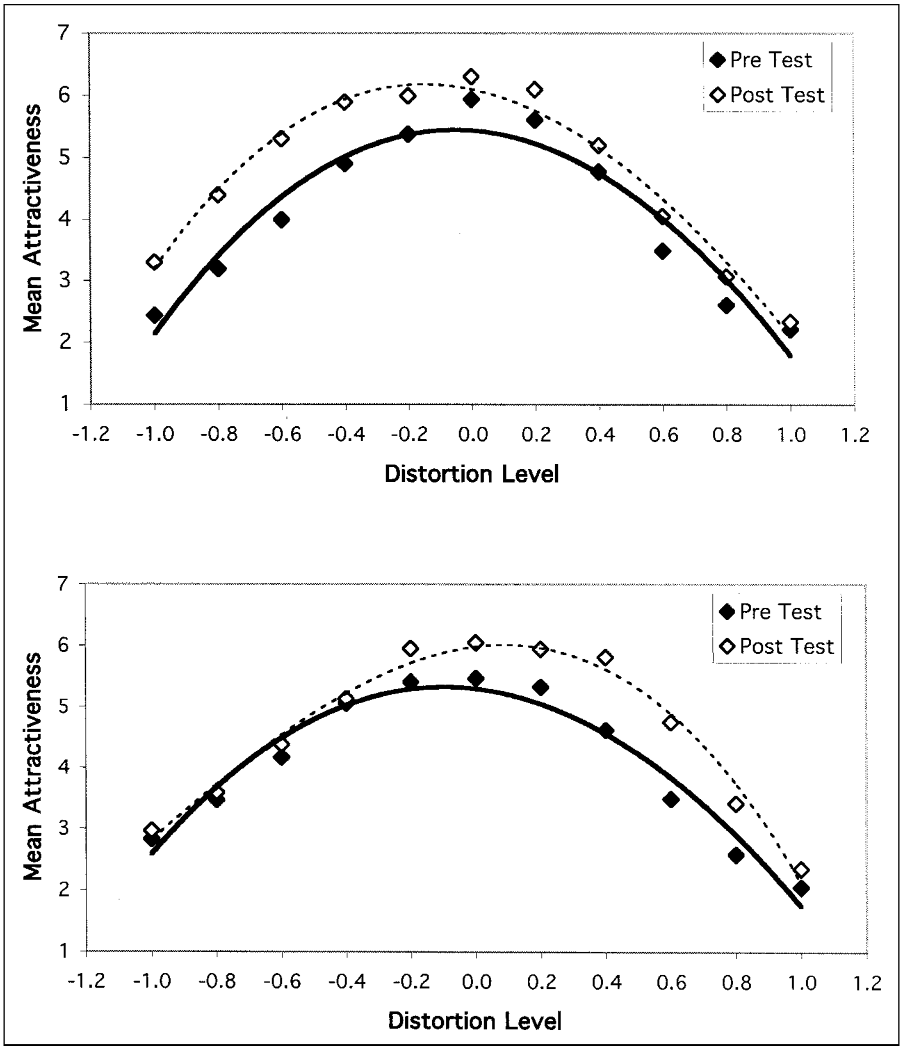

Fig. 6. Mean attractiveness as a function of distortion level, before and after adaptation to negative (laterally compressed; top graph) and positive (laterally expanded; bottom graph) distortions in Experiment 2. Ratings were made on a scale from 1, *unattractive*, to 9, *attractive*. Fitted third-order polynomials are shown.

retinal position (orientation) of adapting and test faces, indicating some contribution of adaptation of high-level, nonretinotopically organized coding mechanisms.

GENERAL DISCUSSION

We found that brief exposure to configurally distorted faces caused the face judged as most attractive to shift toward the adapting distortion. This shift matched a shift in what looked normal, as predicted, for all four types of distortion used (concentrically compressed or expanded, laterally compressed or expanded). These results suggest that perceptual adaptation can rapidly renormalize face-space[3] to reflect consistent changes in the faces people experience, and that preferences are calibrated to match whatever physical characteristics are prototypical. The results also suggest that the appeal of average faces reflects their central location in a distribution, rather than any intrinsic appeal of particular physical characteristics (actual nose size, face shape, etc.), because those physical characteristics become less attractive if they become less prototypical.

The attractiveness aftereffect has two components. The first results from adaptation to consistently distorted faces, which shifts the mean of the face-space distribution toward the adapting distortion. The second is a change in perceived facial attractiveness, which parallels the shift in the mean. This aftereffect occurs because attractiveness judgments are sensitive to the distribution of faces in face-space, favoring average faces. The attractiveness aftereffect can alter which faces look most attractive and can even reverse preferences. For example, before adaptation to compressed faces, undistorted faces are preferred to slightly compressed faces, but after adaptation, the preference reverses.

3. Whether this functional change reflects adaptation of face-specific neurons or more general shape-coding mechanisms remains unclear—see the discussion later in this section.

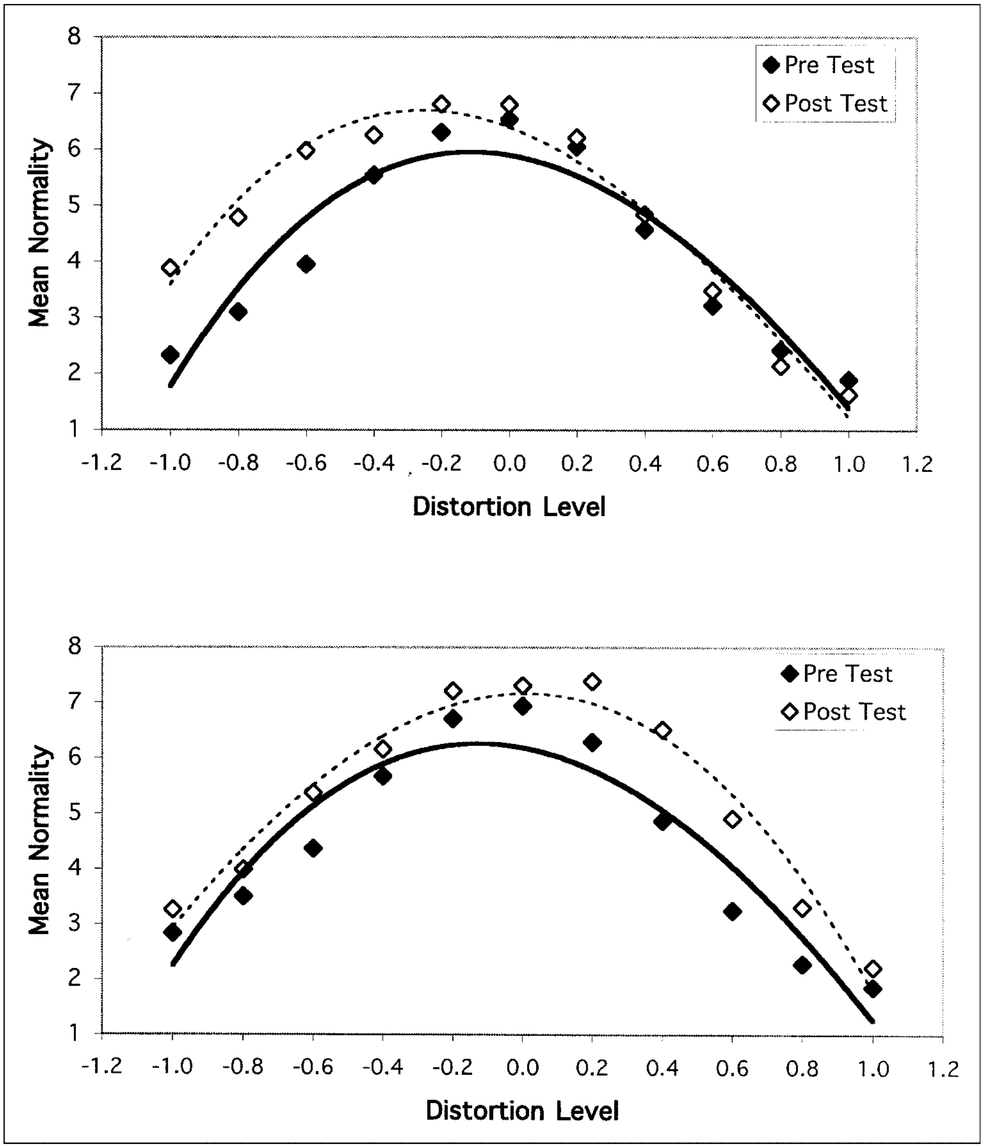

Fig. 7. Mean normality as a function of distortion level, before and after adaptation to negative (laterally compressed; top graph) and positive (laterally expanded; bottom graph) distortions in Experiment 2. Ratings were made on a scale from 1, *unusual*, to 9, *normal*. Fitted third-order polynomials are shown.

The mechanism of preference adjustment may be deceptively simple, in that to the perceiver the face that looks most normal after adaptation may look just like the face that looked most normal before adaptation. Nevertheless, after adaptation, the physical characteristics that look normal, and therefore attractive, have changed to reflect consistent properties of recently seen faces. Despite the simplicity of the mechanism, the functional consequences are likely to be far from trivial. Attractiveness judgments have a powerful impact on person perception, social interactions, and mate choice (Rhodes & Zebrowitz, 2002). Attractive individuals are favored in all these contexts, and their social outcomes are enhanced. Retuning of preferences will, therefore, change which individuals benefit from this positive treatment. It may also make people vulnerable to media manipulation, so that repeated exposure to a diet of similar faces depicting this year's "look" changes standards of beauty. The durability of these changes remains to be determined.

The normality and attractiveness aftereffects occurred despite changes of orientation (+45° vs. −45°) between study and test, indicating some contribution of adaptation in high-level neurons, which are not retinotopically organized. Zhao and Chubb (2001) have reported that the face normality aftereffect survives changes in size, which also implicates high-level neurons, because low-level neurons do not show size invariance. Taken together, these results provide initial converging evidence for adaptation of high-level neurons. A systematic investigation of the relative contributions of low- and high-level adaptation to these aftereffects will be an important topic for future research.

Another important question for future research is whether or not the high-level mechanisms that contribute to these aftereffects are face-

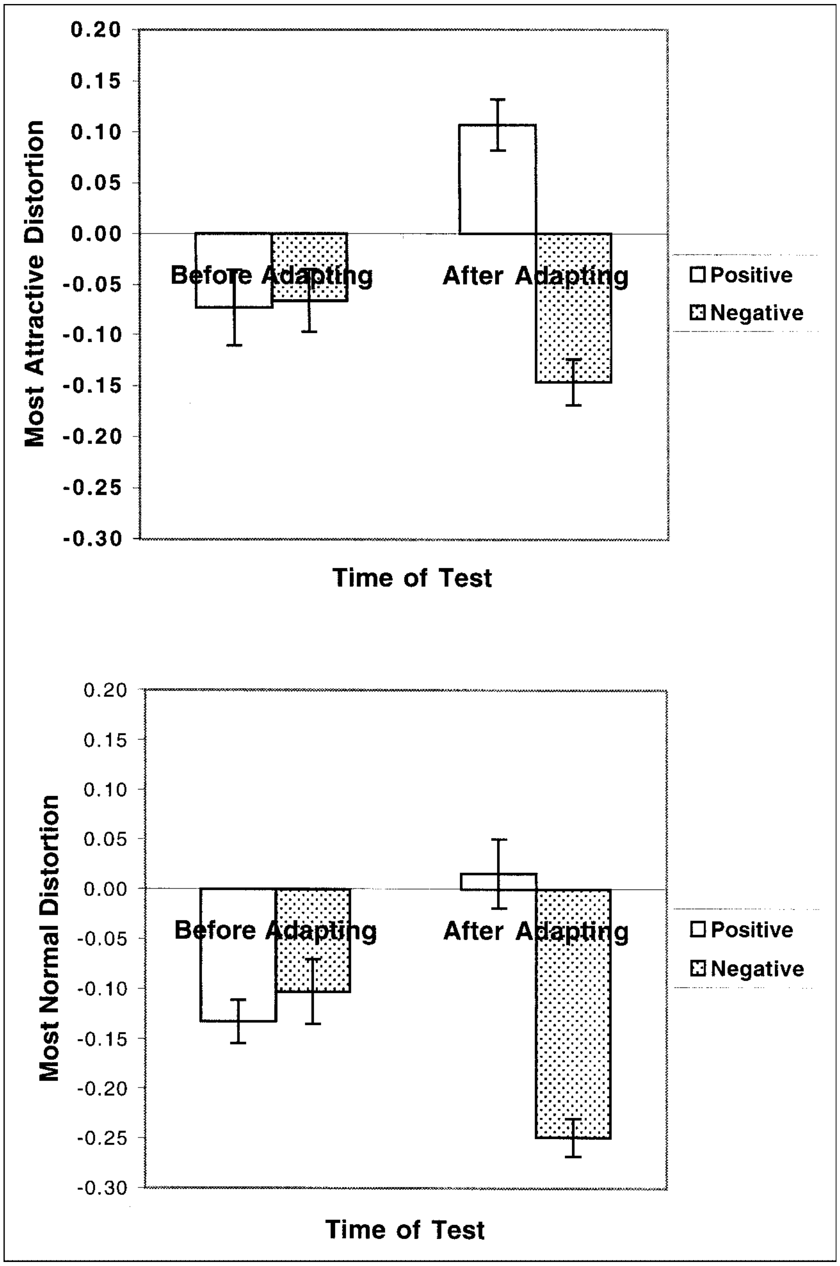

Fig. 8. Distortion chosen as most attractive (top) and most normal (bottom) before and after adapting to negative (laterally compressed) and positive (laterally expanded) distortions in Experiment 2.

specific (Farah, 1996; Kanwisher, 2000). Functional brain-imaging results, showing rapid habituation of responses in the human fusiform face area to repeated faces (e.g., Gauthier et al., 2000), suggest that adaptation of face-coding neurons can occur, but the behavioral evidence is less clear. Webster and MacLin (1999) compared normality aftereffects for upright and inverted faces, reasoning that if face-specific mechanisms are engaged, then the aftereffects should be larger for upright than inverted faces because only the former engage face-specific mechanisms. The aftereffects were very similar for upright and inverted faces (cf. face identity aftereffects; Leopold et al., 2001). These findings could be taken as evidence against adaptation of face-specific mechanisms. However, recent functional magnetic resonance imaging results show that inverted faces strongly activate the fusiform face area (Haxby, Hoffman, & Gobbini, 2000), so these findings may be compatible with adaptation of face-specific mechanisms. We conclude that adaptation of high-level coding mechanisms contributes to face aftereffects, but that future research must determine whether these mechanisms are face-specific or not.

It is well known that exposure increases liking (Bornstein, 1989; Zajonc, 1968), and exposure to faces can increase their attractiveness

(Rhodes, Halberstadt, & Brajkovich, 2001). The present study, which used different faces in the adapting and test phases, shows that effects of exposure can generalize to more abstract properties, such as a particular configural distortion. Similar generalization has been observed for liking of grammatical forms (Gordon & Holyoak, 1983; Manza, Zizak, & Reber, 1998). Most important, our results show that exposure affects attractiveness across an entire continuum of distortions, and that the shift in optimal attractiveness reflects a shift in what looks most normal or average.

Our results suggest that prototypicality or averageness is attractive, but why do people have such a preference? One possibility is that it is evolutionarily adaptive (Thornhill & Gangestad, 1999). Facial averageness correlates with health during development (Rhodes, Zebrowitz, et al., 2001), so that a preference for average faces could have enhanced the reproductive success of human ancestors by helping them select healthy mates. Such a preference might also have enhanced reproductive success by tuning preferences to local population characteristics, which may be optimally adapted to local conditions (assuming limited mobility), or simply by ensuring that an acceptable mate is found. A preference for average faces could also be a by-product of more general prototype-abstraction mechanisms used in recognition and categorization (Rosch, 1973). Evidence that average exemplars are attractive for many things other than potential mates (e.g., dogs, fish, birds, cars, wristwatches) supports this view (Halberstadt & Rhodes, 2000, 2003).

In conclusion, we suggest that perceptual adaptation may be a mechanism by which face-space can be renormalized to reflect ongoing changes in the faces experienced and preferences can be tuned to match those characteristics. However, it is unlikely to be the only mechanism. Its power lies in its rapid response to change, but the effects may be short-lived. Other calibration mechanisms may be needed to abstract prototypes or averages over longer time frames. It can take a long time to acquire expertise with a new population of faces (e.g., another race), suggesting that longer-term mechanisms may also be operating. Future research will need to identify these longer-term mechanisms and examine how they relate to and interact with the more rapid processes of perceptual adaptation that fit the mind to the world.

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