

Transfer of gender aftereffects in face silhouettes reveals face-specific mechanisms

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Abstract

Profile face silhouettes have recently been used to generate a behaviorally validated face space. An important method for studying perceptual spaces is the elicitation of aftereffects, shifts in perceptual judgments that occur after prolonged exposure to stimuli that occupy one locus in the perceptual space. Here we show that face silhouettes elicit gender aftereffects (changes in gender judgments following exposure to gendered faces) in a rapid, implicit adaptation paradigm. Further, we observe that these aftereffects persist across image transformations that preserve the perception of a silhouette as a face but not across transformations that disrupt it. Moreover, the aftereffects transfer between two-tone, profile-view silhouettes and gray-scale, front-view face photographs. Together these results suggest that gender processing occurs at a high level of visual representation and can be parametrically investigated within the silhouette face space methodology.

Keywords: Face adaptation; gender aftereffects; face silhouettes.

Introduction

A number of recent studies have shown that aftereffects similar to those found in color and visual motion are also present in high-level visual domains. These “figural aftereffects” have been observed in the domain of face perception (e.g., Webster & MacLin, 1999; Rhodes et al., 2003). In such studies, prolonged exposure to a face with a certain characteristic causes subsequently viewed faces to appear to have more of the opposite characteristic. For example, viewing a face that is distorted by a contracting transformation causes subsequently viewed normal faces to appear expanded (Webster & MacLin, 1999). Prolonged viewing of a male face causes subsequently viewed gender-neutral faces to appear female (Webster et al., 2004). These behavioral aftereffects are critical to our understanding of face representation because they are thought to reflect the underlying neural mechanisms that respond and adapt to different facial characteristics. For instance, prolonged exposure to a male faces shifts the perceptual gender boundary toward female faces, causing previously neutral-looking faces to appear female, and vice versa. One interpretation of this result is that gender representation (and face processing more generally) is norm-based, such that face-related neural mechanisms code for gender and other features as particular deviations away from a norm, or mean face (e.g., Leopold et al., 2001).

Another aspect of face aftereffects that has influenced our understanding of face representation is the degree to which face aftereffects are robust to transformations between the adaptor and the target. For example, studies have shown that aftereffects subside when the adaptor and target faces differ in their race (e.g. Jaquet, Rhodes, Hayward, 2008) and that simultaneous but opposite aftereffects can be driven by upright and inverted adaptor faces, suggesting that there are distinct representational resources for upright and inverted faces (Rhodes et al., 2004). Other image transformations, such as changes in size between the adaptor and the target, have relatively smaller effects on the transfer of aftereffects (Zhao & Chubb, 2001) suggesting that the underlying representations show a degree of invariance to these changes. These results are taken as evidence that face adaptation reflects a change in tuning of high level neural mechanisms that represent faces, as opposed to simply a conjunction of more generic visual mechanisms that code for contrast, shape, or orientation.

While several researchers have begun to explore these invariances and contingencies, a systematic analysis of the relationship between adaptors and targets across the space of human faces has been limited by the complexity of the face domain itself (but see Leopold et al., 2001). We propose that using a more simplified parameterization of face space can be instrumental for quantifying the role of different facial dimensions in describing the dynamics of face adaptation and representation.

We have recently developed a parameterized face space based on profile face silhouettes (Davidenko, 2007; Figure 1). Face silhouettes provide enough information for accurate judgments of gender, age, and race, reliable ratings of attractiveness, and distinctiveness that correspond to ratings of front-view faces, elicit a face-inversion effect like front-view faces (see Yin, 1969), and selectively activate face-selective regions in the fusiform gyrus (Davidenko et al., 2007). Critically, face silhouettes lend themselves to a simple yet exhaustive parametric representation. A principal components analysis (PCA) of the contours of a large collection of face profiles selected from the FERET database (Phillips et al. 2000; Phillips et al., 1998; Figure 1A) generates a behaviorally validated 20-dimensional silhouette face space that captures the variation of human face silhouettes (Figure 1B). This parameterization allows us to (1) characterize the physical dimensions that affect judgments of gender, race, distinctiveness, and other facial

characteristics, and (2) generate novel face silhouettes with desired values on these characteristics. Here we use these stimuli to probe the representation of face gender by implementing a novel rapid, implicit adaptation paradigm.

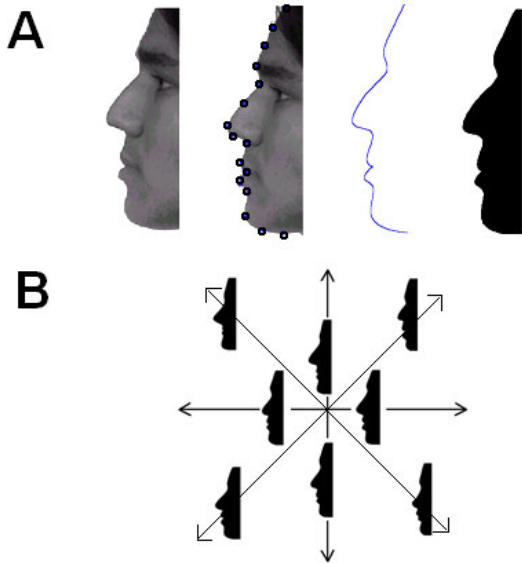


Figure 1. (A) Steps in the parameterization of a silhouette: keypoints are placed along the contour of a profile face image so that they correspond across many faces, the keypoints are interpolated with splines, and the resulting contour is filled in. (B) A sampling of silhouette face space, where the center of the space represents the mean silhouette.

Method

Rapid implicit adaptation

We recently developed a *rapid, implicit adaptation* method (Davidenko, Witthoft, & Winawer, 2008) to test whether face silhouettes elicit gender aftereffects and whether these aftereffects are robust to various image transformations. We constructed a set of 8 male and 8 female “adaptor” silhouettes by sampling along an axis of silhouette face space shown to be highly correlated with gender ratings (Figure 2), and a 9th gender-neutral “target” silhouette defined as the center of silhouette face space. Subjects completed a one-page questionnaire consisting of 9 face silhouettes (Figure 3) as part of a survey administered to Introduction to Psychology students. The first 8 silhouettes were either all female or all male adaptors, similar to the endpoints on the gender axis in Figure 2. To make the 8 male or 8 female faces look different from one another, they varied randomly along dimensions of silhouette space that were not correlated with gender perception. The 9th silhouette was always the same gender-neutral silhouette (middle stimulus in Figure 2). The 8 adaptors were rated on attractiveness, race, or age, and only the target silhouette was rated on gender. We refer to this method as “rapid” adaptation because subjects completed the questionnaire in about one minute, as contrasted with top-up methods that require an initial adaptation period and many subsequent

tests (e.g., Webster & MacLin, 1999). We believe this method is also “implicit” because subjects were not instructed to attend to gender of the 8 adaptor stimuli. They simply provided 9 ratings on the silhouettes and were not aware that some silhouettes were adaptors while the last silhouette was the target. This implicit design was meant to reduce possible effects of response bias in subjects’ gender judgments. A practical advantage of this general methodology is that we can measure aftereffects in a single survey questionnaire, without requiring extensive psychophysics on any individual subject. Previous results (Davidenko, 2007), as well as a baseline study (Figure 2) have validated this survey method as a means of providing reliable, parametric judgments across a variety of stimulus manipulations.

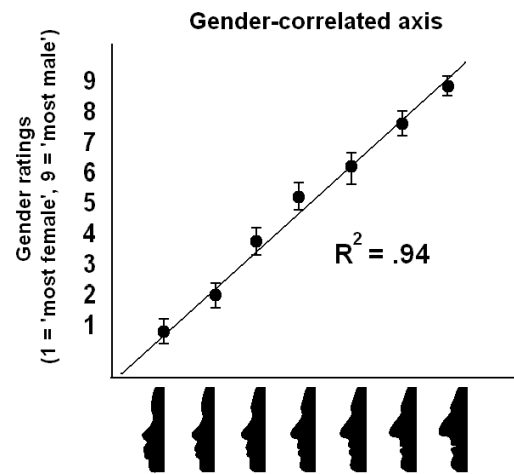


Figure 2. An axis of silhouette face space highly correlated with ratings of gender. Stimuli similar to the female and male endpoints were used as female and male adaptors.

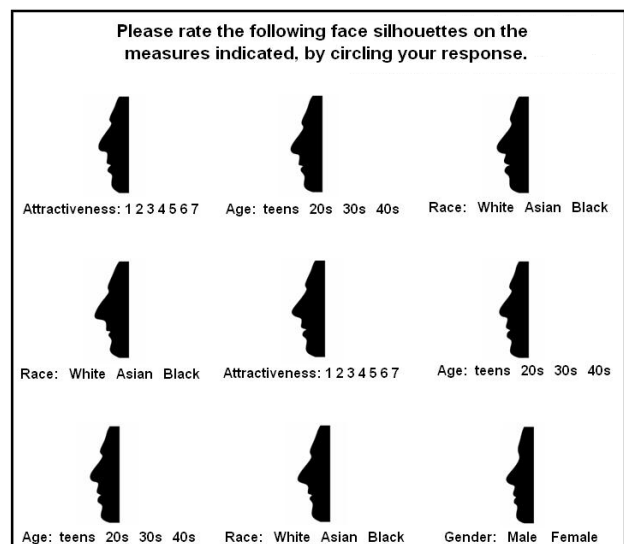


Figure 3. A sample questionnaire used in Study 1. The first 8 silhouettes are male adaptors to be rated on attractiveness, age, or race, and the 9th silhouette is the gender-neutral target to be rated on gender.

In 5 studies, we tested whether face silhouettes elicit gender aftereffects (Study 1), whether the aftereffects are robust to transformations in the contrast polarity (Study 2), left-right orientation (Study 3), and vertical inversion (Study 4) of the adaptors, and whether the aftereffects transfer between face silhouettes and gray-scale, front-view face images (Study 5). In a 6th study we replicated studies 1 and 3, except that the target face and 8 additional gender-neutral targets were placed on the back side of the sheet. This allowed us to test whether the aftereffects depended on the simultaneous exposure to the adapting and target faces, or whether the effects persisted over time.

Study 1: Baseline gender aftereffects

Of 122 subjects who participated in the first study, 59 were randomly assigned to the *adapt-female* condition, and 63 to the *adapt-male* condition. The variable of interest was the proportion of female responses to the target silhouette, as a function of the adaptation condition. Only 2 of 59 *adapt-female* subjects rated the target silhouette as “female”, compared to 39 of 63 *adapt-male* subjects (Chi-square(1)=47, $p < .001$), equivalent to 79% aftereffect-consistent ratings, significantly above 50% chance (Figure 4-Study1). These results indicate that face silhouettes elicit gender aftereffects, and that these aftereffects can be detected in a rapid, implicit adaptation paradigm. The fact that more judgments consistent with adaptation were obtained in the *adapt-female* condition likely reflects the fact that our “neutral” target face looked slightly male to some of our subjects. This bias is orthogonal to the effect of interest and does not affect our result.

Because face silhouettes are relatively simple stimuli, it is possible that the observed aftereffects were the result of adaptation to low-level aspects of the two-tone images such as local contours (Suzuki & Cavanagh, 1998) rather than adaptation to gender *per se*. In Studies 2, 3, and 4, we tested whether the aftereffects persist when we change image properties of the adaptor silhouettes.

Study 2: Reversing contrast polarity

Reversing the contrast polarity of a silhouette does not obviously alter the interpretation of the stimulus as a face despite reversing the contrast of all local contours (see Figure 4-Study2). Here we used the same procedure and stimuli as in Study 1, except that the 8 adaptor face silhouettes were white silhouettes on black background, while the gender-neutral target remained black-on-white. If the aftereffects observed in Study 1 were the result of contrast-specific contour adaptation, they should be eliminated in this manipulation. In fact, only 4 of 42 *adapt-female* subjects, compared to 29 of 39 *adapt-male* subjects, rated the target silhouette as “female” (Chi-square(1)=35, $p < .001$), indicating 83% aftereffect-consistent ratings, again well above chance. Thus, face silhouettes elicit gender aftereffects that are robust to changes in contrast polarity between the adaptor and target stimuli.

Study 3: Reversing left-right orientation

Next we considered the possibility that the aftereffects could be explained by local shape or curvature adaptation (see Suzuki and Cavanagh, 1998). To reduce the contribution of local shape adaptation, we flipped the 8 adaptor face silhouettes horizontally so that they faced right, while the target remained facing left). Only 8 of 50 *adapt-female* subjects, compared to 37 of 44 *adapt-male* subjects, rated the target as “female” (Chi-square(1)=18, $p < .001$), indicating 84% aftereffect-consistent ratings. These results suggest that the aftereffects cannot be explained by low-level shape adaptation alone. In the next manipulation, we tested whether aftereffects were also robust to vertical inversion of the adaptors.

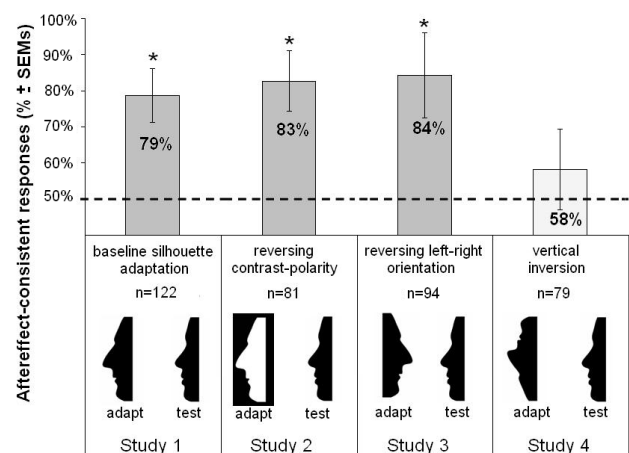


Figure 4. Percent of aftereffect-consistent ratings of the gender-neutral silhouette in Studies 1 through 4. Strong gender aftereffects were observed in the baseline (Study 1), when the contrast polarity of the adaptors was reversed (Study 2), and when left-right orientation of the adaptors was reversed (Study 3), but not when the adaptors were vertically inverted (Study 4).

Study 4: Vertical inversion

As with face photographs (Yin, 1969), vertical inversion of face silhouettes disrupts behavioral face processing (Davidenko, 2007) and attenuates the response of face-selective fusiform regions (Davidenko et al., 2007). We reasoned that if gender aftereffects depend on face-specific processing and are not simply the result of low-level adaptation, inverting the adaptor stimuli should reduce or eliminate aftereffects. Indeed, with inverted adaptor silhouettes, 19 of 36 *adapt-female* subjects, compared to 29 of 42 *adapt-male* subjects, rated the upright target as “female,” (Chi-square (1)=1.8, $p > .15$), indicating 58% aftereffect-consistent ratings, not significantly different from chance. Thus, gender aftereffects in face silhouettes were not robust to vertical inversion of the adaptors.

Study 5: Transfer across view and image format

The results so far suggest that gender aftereffects are sensitive to transformations that disrupt the face percept

(vertical inversion) but robust to transformations that preserve it (left-right inversion and contrast polarity inversion). To test this hypothesis further, we measured whether aftereffects transfer between face silhouettes (which are in profile view) and gray-scale, front-view face images. Since most image properties differ between these two types of images, any preservation of aftereffects would demonstrate that the aftereffects operate on a high, face-specific level of visual representation. Previous studies using photographs of faces have shown transfer across viewpoint (Jiang et al, 2007). The procedure for this study was the same as in the previous studies, but the aftereffects were tested in two directions: either the adaptor stimuli were real face silhouettes (152 subjects, either *adapt-female* or *adapt-male*) with a gender-neutral, gray-scale, front-view target face constructed with the FaceGen Modeller software from Singular Inversions (Figure 5-Study5a), or the adaptor stimuli were the gray-scale front-view counterparts of the silhouettes and the target stimulus was the gender-neutral face silhouette used in the previous studies (151 subjects; Figure 5-Study5b). Remarkably, gender aftereffects persisted across these drastic changes in face image format, although the size of the effect was smaller than in Studies 1-3. In the *adapt-silhouette* conditions, the proportion of aftereffect-consistent ratings of the front-view target was 60% (Chi Square(1)=5.7, $p < .02$), while in the *adapt-front-view* conditions, the proportion of aftereffect-consistent ratings was 64% (Chi Square(1)=11.6, $p < .001$).

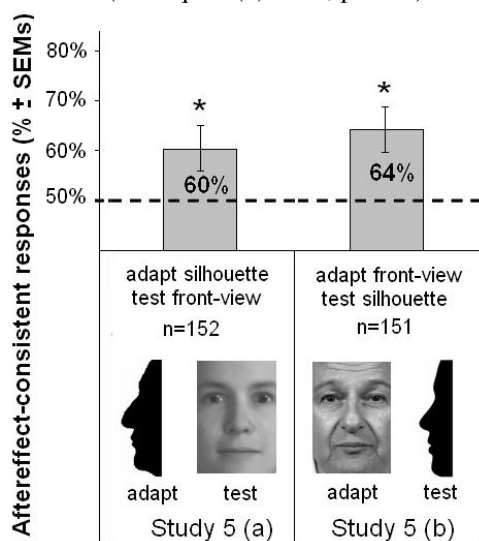


Figure 5. Stimuli used in Study 5. In both the *adapt-silhouette* (left) and the *adapt-front-view* condition (right) conditions, gender aftereffects persisted across drastic view and image changes between adaptor and target faces.

Study 6: Transfer across a page turn

In Studies 1-5, the target face and the adapting faces were all presented on a single sheet of paper, and hence were available for simultaneous viewing. To test whether the observed adaptation effects depended on simultaneous viewing (similar to simultaneous contrast in brightness

perception), or whether the effects persist when the target face is viewed in isolation of the adaptors, we repeated Studies 1 (baseline) and 3 (reversing left-right orientation), except that the study sheet contained two sides: side 1 with adapting faces 1-8, and side 2 with 9 different neutral silhouettes, all rated on gender. The adapting silhouettes on side 1 and the first target silhouette on side 2 were identical to the 9 silhouettes used in Studies 1 and 3, respectively. The dependent variable of interest was the proportion of aftereffect-consistent ratings of the first neutral silhouette on side 2, and we obtained ratings on the subsequent silhouettes to measure whether the aftereffect would persist. In each condition, we observed significant adaptation, similar to Studies 1 and 3: 84% aftereffect consistent judgments in the baseline condition, and 69% in the left-right reversal condition. Furthermore, in the baseline condition, an above-chance proportion of aftereffect-consistent ratings persisted after the first target silhouette was rated (see Figure 6). These results demonstrate that the effect of viewing 8 faces of the same gender alters perception of faces in a way that persists even when novel faces are viewed without the simultaneous context of the adapting faces.

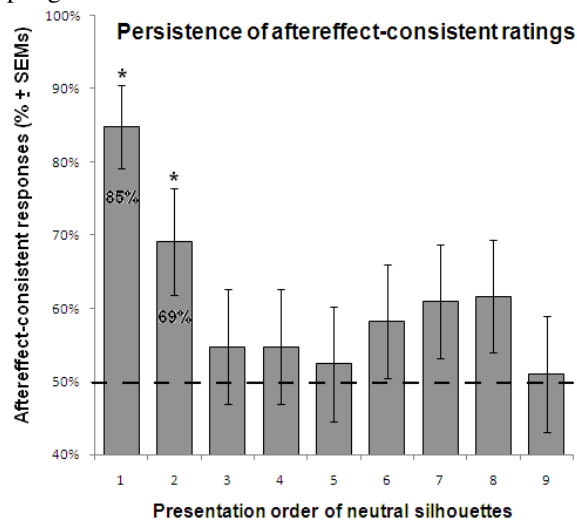


Figure 6. Proportion of aftereffect-consistent ratings of the gender-neutral silhouettes in Study 6, baseline condition (transfer across a page turn). Significant gender aftereffects were observed in the first and second rated stimuli, despite the lack of simultaneous exposure to the adaptors and target.

Discussion

Our results show that gender aftereffects are robust to transformations that preserve the face percept, even when the transformations result in drastic image differences between adaptors and target faces. Eight simple judgments made on profile silhouettes were sufficient to alter a subsequent judgment on a front-view face photograph, and vice versa. The transfer of gender aftereffects between two-tone, profile-view face silhouettes and gray-scale, front-view face photographs suggests these vastly different formats of a face image share an underlying neural

representation. When the gender boundary is shifted in silhouettes, it is also shifted for front-view images, indicating that gender representation occurs at a highly abstract level of visual representation.

Furthermore, we have shown that a rapid, implicit adaptation paradigm can be effectively used to detect gender aftereffects. Although the data obtained in this paradigm represent only a single point in a psychometric curve (specifically, the probability of labeling a neutral face as male or female), this data can be gathered quickly across many subjects and does not require extensive psychophysical testing. Because subjects were not directed to attend to the gender of the adapting faces, and because there were not distinct “adapt” and “target” phases of the study, the adaptation paradigm is implicit, reducing the possibility of task demands biasing subjects’ responses.

Finally, our results demonstrate for the first time that gender aftereffects, which have been previously found with gray-scale front-view face images, also occur in two-tone, profile-view face silhouettes. The transfer of aftereffects between silhouettes and front-view images suggests that gender processing in face silhouettes shares common mechanisms with gender processing in front-view faces, despite the drastic image differences between the two types of faces. This provides further validation of the face silhouette methodology and suggests that parameterized face silhouettes can contribute to our understanding of the dynamics of gender adaptation and face representation in general. The finding that the aftereffects persist when the target silhouettes are rated without the context of the adapting faces (Study 6) demonstrates that briefly viewing a small number of face silhouettes can cause a temporary shift in the calibration of face-specific judgments, consistent with the notion that face adaptation reflects a process that normalizes perception to the statistics of the environment.

A key advantage of using face silhouettes is that they provide a fully parameterized face space and, in particular, the ability to construct face stimuli at any desired position in face space. In addition to constructing face stimuli that are more or less male, we can also construct face silhouettes at specified distances from the norm face silhouette, or at particular angular distances from other face silhouettes. This ability will allow us to quantify face aftereffects in a way that cannot be achieved using photographs or non-parameterized face stimuli. For example, we can test “how male” a face must be in order to elicit an aftereffect, or how the size of the aftereffect compares to the distortion of the adaptor face. We can also test predictions made by norm-based models of face adaptation. By constructing face stimuli at specified positions in face space, we can determine whether adaptation aftereffects always shift perceptual boundaries across the mean face, or whether there are instances in which the aftereffect shifts perception in other directions. Addressing these questions will allow us to further quantify the mechanisms of face adaptation, and ultimately further our understanding of face representation.

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