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Gender aftereffects in face silhouettes reveal face-specific mechanisms

Nicolas Davidenko
Department of Psychology, Stanford University, Stanford, CA, USA

Nathan Witthoft and Jonathan Winawer
Department of Psychology, Stanford University, Stanford, CA, and Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, Cambridge, MA, USA

Recently a parameterized face space has been created using profile face silhouettes (Davidenko, 2007). Face silhouettes provide enough information for accurate judgements of age, gender, attractiveness, and race, and their parameterization allows us to characterize the physical factors that affect these judgements. Here we use these stimuli to further probe the representation of face gender, by implementing a novel rapid, implicit adaptation paradigm. Using this paradigm, we first show that gender aftereffects like those found with textured front-view faces (e.g., Webster, Kaping, Mizokami, & Duhamel, 2004) occur with face silhouettes. Furthermore, these aftereffects transfer across changes in contrast polarity and left–right orientation of the adapting silhouettes, neither of which affect the perception of a silhouette as a face; however, vertically inverting the adapting stimuli greatly reduces aftereffects. Finally, we show that adapting to silhouettes alters gender judgements of front-view faces, and vice versa, suggesting that gender processing in front-view faces and silhouettes relies on common neural mechanisms, and that these are the site of the adaptation effect. We conclude that face silhouettes provide a useful tool to test hypotheses about face space representation.

Address correspondence to Nicolas Davidenko, Department of Psychology, 450 Serra Mall, Building 420, Stanford, CA 94107, USA. E-mail: ndaviden@psych.stanford.edu

METHOD: RAPID IMPLICIT ADAPTATION

The stimuli were eight male and eight female parameterized "adapting" face silhouettes, and one gender-neutral "target" face silhouette (see Davidenko, 2007). Participants completed a one-page questionnaire consisting of nine face silhouettes (Figure 1A). The first eight adapting silhouettes were either all female or all male, and the ninth silhouette was always the same gender-neutral target. The first eight (adapting) silhouettes were rated on attractiveness, race, or age, and only the ninth (target) silhouette was rated on gender. We refer to this as "rapid, implicit adaptation" because participants completed the questionnaire in about 1 minute and were not instructed to

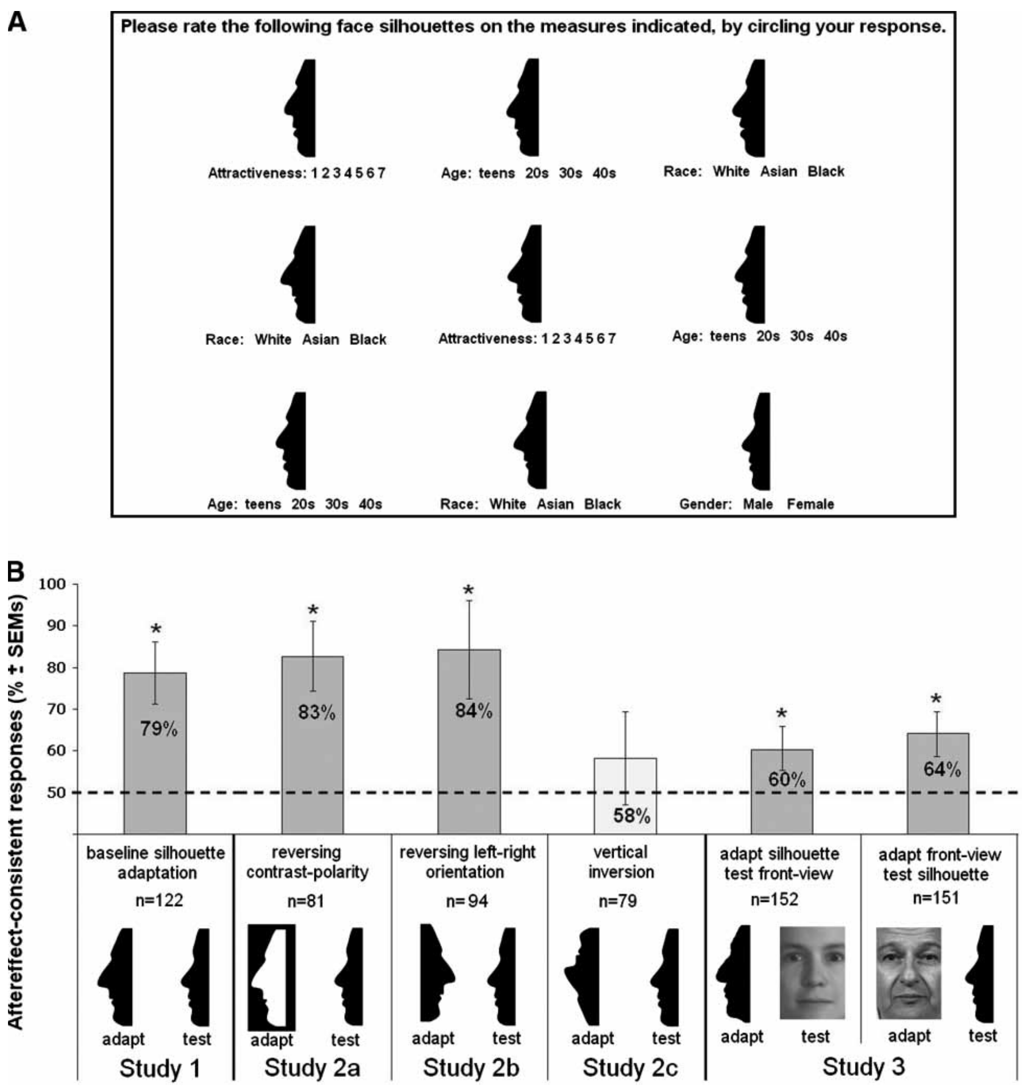

Figure 1. (A) A sample questionnaire used in Study 1. (B) The summary of results from Studies 1, 2, and 3 as the percentage of aftereffect-consistent responses compared to chance level.

attend to gender of the eight adapting stimuli; they simply provided nine ratings on the silhouettes.

STUDY 1: GENDER AFTEREFFECTS

One hundred and twenty-two participants were assigned to either the adapt-female or the adapt-male condition. The response to the target silhouette was the variable of interest. Only 2 of the 59 adapt-female participants rated the target silhouette as "female", compared to 39 of the 63 adapt-male participants, $\chi^2(1) = 47$, $p < .001$, equivalent to 79% aftereffect-consistent ratings (Figure 1B). Gender aftereffects thus occur with face silhouettes, and they can be elicited in this rapid, implicit adaptation paradigm.

Do the observed aftereffects reflect adaptation to faces per se, or can they be explained by adaptation to low-level image properties?

STUDY 2A: 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. This study used the same procedure and stimuli as in Study 1, except that the eight adapting face silhouettes were white-on-black. The gender-neutral target remained black-on-white. Only 4 of the 42 adapt-female participants, compared to 29 of the 39 adapt-male participants, rated the target silhouette as "female", $\chi^2(1) = 35$, $p < .001$, equivalent to 83% aftereffect-consistent ratings. Thus, gender aftereffects in silhouettes transfer across changes in contrast polarity.

STUDY 2B: REVERSING LEFT–RIGHT ORIENTATION

Next we considered the possibility that the gender aftereffects could be explained by local shape or curvature adaptation (see Suzuki & Cavanagh, 1998). To reduce the contribution of shape adaptation, we flipped the eight adapting face silhouettes so that they faced right (while the target remained facing left). Only 8 of the 50 adapt-female participants, compared to 37 of the 44 adapt-male participants, rated the target as "female", $\chi^2(1) = 18$, $p < .001$, equivalent to 84% aftereffect-consistent ratings, suggesting that the gender aftereffects cannot be explained by low-level shape adaptation alone.

STUDY 2C: VERTICAL INVERSION

As with face photographs, vertical inversion of face silhouettes impairs face processing (Davidenko, 2007; Yin, 1969). We reasoned that if gender aftereffects depend on face-specific processing, inverting the adapting stimuli should reduce aftereffects. Indeed, with inverted adapting silhouettes, 19 of the 36 adapt-female participants, compared to 29 of the 42 adapt-male participants, rated the upright target as "female", showing no significant effect of adapting condition, $\chi^2(1) = 1.8$, $p > .15$, equivalent to 58% aftereffect-consistent ratings.

STUDY 3: TRANSFER ACROSS IMAGE FORMAT

The results so far suggest that gender adaptation is invariant to transformations that preserve the face percept. To test this hypothesis further, we measured whether aftereffects transfer between profile face silhouettes and greyscale front-view faces. Since most image properties are different between these two image formats, any preservation of aftereffects would demonstrate that the aftereffects operate on a high, face-specific level of visual representation. The procedure for this study was the same as in the previous studies, but with four conditions: Either the adapting stimuli were silhouettes (152 participants, either *adapt-female or adapt-male*) with a gender-neutral, greyscale, front-view target face constructed with the Face Modeler software, or the adapting stimuli were the greyscale front-view counterparts of these silhouettes and the target stimulus was the gender-neutral face silhouette used in the previous studies (151 participants). Remarkably, gender aftereffects persisted across these drastic changes in face image format. In the adapt-silhouette conditions, the proportion of aftereffect-consistent ratings of the front-view target was 60%, $\chi^2(1) = 5.7$, $p < .02$, and in the adapt-front-view conditions, the proportion of aftereffect-consistent ratings was 64%, $\chi^2(1) = 11.6$, $p < .001$.

Our results suggest that gender processing and adaptation occur, at least in part, at a high level of visual representation that is relatively insensitive to image transformations that preserve the face percept. Corroborating recent fMRI evidence that face silhouettes elicit selective activity in the fusiform face area (Davidenko, Remus, Glover, & Grill-Spector, 2007), we have shown evidence that gender processing in face silhouettes shares common mechanisms with gender processing in front-view 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 representation and adaptation in the general face domain.

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Object-based storage in visual working memory and the visual hierarchy

Tao Gao

Zhejiang University, Hangzhou, Zhejiang Province, P. R. China, and Yale University, New Haven, CT, USA

Mowei Shen, Zaifeng Gao, and Jie Li

Zhejiang University, Hangzhou, Zhejiang Province, P. R. China

How visual information is represented in visual working memory has been extensively studied in the past decade. Luck and Vogel (1997) proposed a "strong object" hypothesis, suggesting that the capacity of working memory is limited by the number of objects, regardless of the complexity of each object. However, other studies showed that the capacity drops and the object-based benefits in storage disappear when the memory items become complex (Alvarez & Cavanagh, 2004; Olson & Jiang, 2002; Xu, 2002). Olson and Jiang (2002) put forward a "weak object" hypothesis, suggesting that working memory is limited by both the number of objects and the composition of those objects. However, it is still unclear why object-based benefits are weak in working memory. Most importantly, how can theories

Address correspondence to Tao Gao, Department of Psychology, Yale University, New Haven, CT, 06520-8205, USA. E-mail: Tao.Gao@yale.edu