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The Role of Familiarity on Viewpoint Adaptation for Self-Face and Other-Face Images

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Abstract

An adaptation method was used to investigate whether self-face processing is dissociable from general face processing. We explored the viewpoint aftereffect with face images having different degrees of familiarity (never-before-seen faces, recently familiarized faces, personally familiar faces, and the participant's own face). A face viewpoint aftereffect occurs after prolonged viewing of a face viewed from one side, with the result that the perceived viewing direction of a subsequently presented face image shown near the frontal view is biased in a direction which is the opposite of the adapting orientation. We found that (1) the magnitude of the viewpoint aftereffect depends on the level of familiarity of the adapting and test faces, (2) a cross-identity transfer of the viewpoint aftereffect is found between all categories of faces, but not between an unfamiliar adaptor face and the self-face test, and (3) learning affects the processing of the self-face in greater measure than any other category of faces. These results highlight the importance of familiarity on the face aftereffects, but they also suggest the possibility of separate representations for the self-face, on the one side, and for highly familiar faces, on the other.

Keywords

Face adaptation, face representation, viewpoint aftereffects, familiar faces, plasticity

Introduction

The self-face is a unique and important stimulus. Self-face recognition contributes to the sense of personal identity and to the development of self-knowledge (or awareness) from childhood (Suddendorf & Butler, 2013; Suddendorf, Simcock, & Nielsen, 2007; Sugiura, 2015). A large number of studies provide evidence that self-face processing differs from the processing of another person's face, although it is debated whether such results should be attributed to the uniqueness of the self-face or, instead, to the fact that the self-face is a highly over-learned stimulus (Kircher et al., 2001). Within this debate, the technique of adaptation

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has been proposed as a tool that may provide useful information for understanding whether the self-face and familiar faces are processed by similar or different underlying mechanisms.

Adaptation has been mainly studied in low-level vision. It is well known, for example, that prolonged viewing of a tilted test line or grating (e.g. 45° left) can reduce the sensitivities of neuronal populations encoding that orientation, which results in a visual aftereffect leading a subsequently viewed upright stimulus to appear tilted in the opposite direction (Jin, Dragoi, Sur, & Seung, 2005). However, visual aftereffects can also be observed with more complex stimuli, such as faces (Clifford et al., 2007). Face viewpoint adaptation, for example, is the phenomenon in which adaptation to a face that is rotated about a vertical axis in one direction (e.g. 30° left away from frontal pose) induces a bias in the opposite direction in the subsequent perception of face orientation (Fang & He, 2005). It has been proposed that the transfer of the viewpoint aftereffect depends on the presence of view-selective face neurons in the human visual system (Fang & He, 2005; Fang, Ijichi, & He, 2007; Leopold, O'Toole, Vetter, & Blanz, 2001).

Previous studies employing the self-face, familiar faces, and unfamiliar faces have considered adaptation to face images with various degrees of distortion (Rooney, Keyes, & Brady, 2012; Walton & Hills, 2012). However, the use of distorted faces may not be optimal for studying self-face processing (Strobach & Carbon, 2013). Consequently, in the present study, the specialization of self-face processing will be examined by measuring the face viewpoint aftereffect, which does not involve any distortion of the three-dimensional structure of the face.

Given the central role that learning plays in distinguishing self-face processing from the processing of another person's face, we generated a sense of familiarity in the laboratory with the technique proposed by Ryu and Chaudhuri (2006), producing a controlled amount of learning. The 'to be learned' faces were repeatedly presented in a sequential manner to participants for 1 s, with different orientations with respect to the frontal, together with their fictional name and surname, occupation, and place of residence. Before presenting the hypotheses motivating the present study, in the next sections we will briefly summarize the literature on the effects of familiarity on face processing and the evidence for the specificity of self-face processing.

Familiarity and face processing

Although humans are thought to be 'face experts' (e.g. Schwaninger, Carbon, & Leder, 2003), face processing is strongly affected by the level of familiarity. Familiar faces, as opposed to unfamiliar faces, allow identity recognition also in degraded stimulus conditions (Burton, Wilson, Cowan, & Bruce, 1999), have been shown to rely on specialized neural pathways (Duarte, Ranganath, Winward, Hayward, & Knight, 2004; Eger, Schweinberger, Dolan, & Henson, 2005) involved in the retrieval of 'person knowledge' (Gobbini & Haxby, 2007), and are detected faster and more accurately even under reduced attentional resources and in the absence of awareness (Gobbini et al., 2013). The recognition of unfamiliar faces degrades more strongly than the recognition of familiar faces as a consequence of a viewpoint change (O'Toole, Edelman, & Bülthoff, 1998), of a change in expression (Bruce, 1982), and of the change of the environmental context in which the face is viewed (Dalton, 1993). For a review, see Johnston and Edmonds (2009).

Differently from unfamiliar faces, the identification of familiar faces is automatic: rapid, non-conscious, and mandatory (Jung, Ruthruff, & Gaspelin, 2013). Differential processing for familiar and unfamiliar faces is supported by Positron Emission Tomography (PET) studies, functional Magnetic Resonance Imaging (fMRI) studies, and event-related potentials studies which, for the two classes of faces, show responses of different amplitudes, distinct sensitivities, and distinct neural activation patterns (Caharel, Jacques, d'Arripe, Ramon, & Rossion, 2011; Pourtois, Schwartz, Seghier, Lazeyras, & Vuilleumier, 2005).

Face familiarity comprises both quantitative and qualitative dimensions. On the one hand, familiarity may reflect the level of previous exposure, with the faces of recent acquaintances being less familiar than the faces of old friends. On the other hand, familiarity may vary in a qualitative manner because familiar faces belong to different categories: our loved ones, our classmates, our relatives, our friends, the self-face, and the faces of famous people. Although, in general, familiarity facilitates face processing, it is not always so. For example, Carbon (2008) measured recognition accuracy both of famous faces and of personally familiar faces and found that even minor modifications to the original images led to a dramatic decline in recognition accuracy for famous faces, whereas recognition accuracy was very robust for the personally familiar faces. According to Carbon, this may be due to the fact that famous faces are processed as 'icons' that are tied to specific pictorial representations. Thus, regardless of their high familiarity, famous faces seem to be processed in a qualitatively different manner than other kinds of familiar faces.

The self-face advantage

Visual search is faster for target images corresponding to the participant's own face, relative to the faces of unfamiliar or familiar others. A 'self-face advantage' has been found in face owner identification (Keenan et al., 1999), in face orientation identification (Caudek & Monni, 2013; Ma & Han, 2010; Sui & Han, 2007), and in face categorization tasks (Ma & Han, 2009). Such a reaction time (RT) advantage persists also after hundreds of presentations of an unfamiliar face (Tong & Nakayama, 1999). In studies examining the capacity of different types of faces (self, friend, stranger) to grab attention when processing self, friend, and stranger names, however, recent evidence suggests that the self-face does not produce a greater amount of distraction in a naming task compared to other types of faces (Devue & Brédart, 2008; Keyes & Dlugokencka, 2014).

Different facets of face adaptation effects

Strobach and Carbon (2013) have described the face adaptation effects according to a conceptual framework comprising three dimensions. The first dimension is associated with the facial information which is susceptible to adaptation. In fact, face aftereffects have been studied by considering different kinds of face properties, such as facial identity ('face-identity aftereffect'; Hurlbert, 2001; Leopold, Rhodes, Müller, & Jeffery, 2005; Rhodes & Jeffery, 2006; Walther, Schweinberger, & Kovacs, 2013), normality (or absence of distortion; 'face-distortion aftereffect'; MacLin & Webster, 2001; Rooney et al., 2012; Walton & Hills, 2012; Watson & Clifford, 2003; Webster & MacLin, 1999), pose ('viewpoint aftereffect'; Bi, Su, Chen, & Fang, 2009; Chen, Yang, Wang, & Fang, 2010; Daar & Wilson, 2012; Fang et al., 2007; Fang & He, 2005; Ryu & Chaudhuri, 2006), ethnic group (Webster, Kaping, Mizokami, & Duhamel, 2004), gender (Webster et al., 2004), facial expressions (Butler, Oruc, Fox, & Barton, 2008), adaptation of gaze direction (Jenkins, Beaver, & Calder, 2006), and systematic distortions of the spatial or figural information of the face ('face figural aftereffect'; Carbon & Ditye, 2012; Carbon & Leder, 2005; Webster & MacLin, 1999). The second dimension is associated with the time interval between adaptation and test. Different studies have considered delays of milliseconds (e.g. Leopold et al., 2001), minutes (e.g. Carbon & Leder, 2006), a one-night sleep (e.g. Ditye, Javadi, Carbon, &

Walsh, 2013), days (Carbon et al., 2007), and even weeks (e.g. Carbon & Ditye, 2011). The third dimension is associated with the transfer of adaptation effects (i.e. the difference between adaptation and test images).

Familiarity and face adaptation

Taken together, the findings in the field of face adaptation research provide evidence that the magnitude of adaptation depends on the level of face familiarity. In order to manipulate familiarity, several studies have used images of famous people (Carbon & Ditye, 2011; Hills & Lewis, 2012; Walther et al., 2013), whereas in other studies participants had been trained with face stimuli (Jiang, Blanz, & O'Toole, 2007, 2009; Ryu & Chaudhuri, 2006). Only a few studies have examined the effects of adaptation by using personally familiar faces (Rooney et al., 2012; Walton & Hills, 2012), or the participant's own face (Laurence & Hole, 2011; Rooney et al., 2012).

Some studies indicate that face familiarity supports greater aftereffects also when the adaptor and test stimuli differ for pose orientation (Jiang et al., 2007) or illuminant direction (Jiang et al., 2009). It has also been shown that, for familiar faces, the aftereffects survive longer time lapses between the presentation of the adaptor and the presentation of the test stimulus, compared to unfamiliar faces (Carbon & Ditye, 2011; Carbon et al., 2007). These results have been interpreted as suggesting that familiar faces are perceptually more 'flexible' than unfamiliar faces, thus allowing an easier transfer of adaptation from one face image to another (Carbon & Ditye, 2011; Carbon et al., 2007).

Other studies have questioned this conclusion. In fact, when the self-face (i.e. a very familiar face) had been used as the adaptor, a smaller aftereffect has been found relative to when the adaptor was a familiar or an unfamiliar face. Laurence and Hole (2011) have interpreted this result as indicating that the processing of the self-face requires a smaller amount of attentional resource and, thus, it produces a smaller level of 'neural fatigue' relative to other kinds of faces, which in turn may explain the reduced aftereffect. Further studies have shown no effect of familiarity on the magnitude of the aftereffect. Rooney et al. (2012) found cross-identity aftereffects characterized by shifts in the perception of attractiveness, normality, and distortedness after exposure to distorted unfamiliar faces, the distorted self-face, and distorted friends' faces. They have interpreted these results as suggesting the existence of a common representation for all classes of faces, regardless of the level of familiarity. Finally, Ryu and Chaudhuri (2006) found that an increased level of familiarity actually interferes with the cross-identity transfer of the viewpoint aftereffect between the adaptor and the test images.

In another recent study, Walton and Hills (2012) used a stimulus set made up of familiar, unfamiliar, and personally familiar (subject's parents) faces. The adaptation task comprised both within-identity and cross-identity trials. Differently from Rooney et al. (2012), they found a transfer of the aftereffect from all adaptor types to all test stimuli, but also a larger magnitude of the aftereffect in the presence of a familiarity match between adaptor and test (e.g. unfamiliar adaptor, unfamiliar test; famous face adaptor, famous face test), except for personally familiar faces (personally familiar faces as adaptors induced smaller aftereffects than other kinds of faces). Walton and Hills have interpreted their results as evidence of different representations for familiar, unfamiliar, and personally familiar faces.

In summary, the results of the studies investigating the effects of familiarity on the transfer of face adaptation do not provide a completely clear and consistent picture. It is important to note that all the studies mentioned above, apart from Ryu and Chaudhuri (2006), examined the face aftereffects by using morphed distorted face images.

Effects of familiarity on face adaptation: Three hypotheses

Three hypotheses have been proposed to explain the effects of familiarity on face adaptation.

Hypothesis 1. Familiar faces are processed differently from unfamiliar faces because they require fewer attentional resources (Gobbini et al., 2013; Tong & Nakayama, 1999). According to this 'attentional' hypothesis, when used as adaptors, highly familiar faces, and the self-face in particular, should produce smaller aftereffects than less familiar faces.

Hypothesis 2. An increased level of familiarity enhances the strength of face adaptation (Jiang et al., 2007). According to this second hypothesis, stronger aftereffects are expected for the self-face and for highly familiar faces, regardless of whether they are used as adaptors or test stimuli, and smaller aftereffects should be found for unfamiliar adaptors and/or test faces.

Hypothesis 3. The self-face is 'special' because it engages neural systems that are physically or functionally distinct from those involved in representing the faces of other people. In an extreme form, this hypothesis predicts no transfer of adaptation between the self-face and other faces (Gillihan & Farah, 2005).

The purpose of the present study is to evaluate these hypotheses by measuring the magnitude of the cross-identity transfer of the viewpoint aftereffect when using as stimuli faces with different degrees of familiarity. We considered (1) wholly unfamiliar faces (never-before-seen faces), (2) familiarized faces (unfamiliar faces to which the participants were exposed for a short amount of time before the experiment), (3) personally familiar faces (the face of a close friend), and (4) the participant's own face. In Experiment 1, we examined the transfer of the viewpoint aftereffect from unfamiliar or from briefly familiarized faces to faces with different levels of familiarity (the self-face, briefly familiarized faces, or unfamiliar faces). In Experiment 2a, we used the self-face as the adaptor with unfamiliar or briefly familiarized test faces. In Experiment 2b, participants were adapted to unfamiliar faces and were then tested with either a real-world familiar face (a close friend's face) or with briefly familiarized faces.

General method

Apparatus and stimuli

Pictures of each participant's own face and of individuals who did not participate in the experiments were taken with a digital camera (Canon PowerShot A490). These images were then processed with Adobe Photoshop CS (Adobe Systems Inc.). All images were converted to greyscale and subjectively equated for luminance and contrast (see Figure 1). All faces were mirror-reversed. Final image size was 384×384 pixels (visual angle of $5.4^\circ \times 5.4^\circ$).

The experiments were controlled by MATLAB (Version 8.5.0; Mathworks, Natick, MA) using the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997) on a PC running Windows XP. Stimuli were presented on a 19-inch video monitor operating at 75 Hz with a screen resolution of 1280×1024 pixels.

Procedure

The plan of the experiments is shown in Table 1. Each experiment consisted of two phases: familiarization and test. Half of the participants underwent the familiarization phase whereas the remaining half did not (they only completed the test phase).

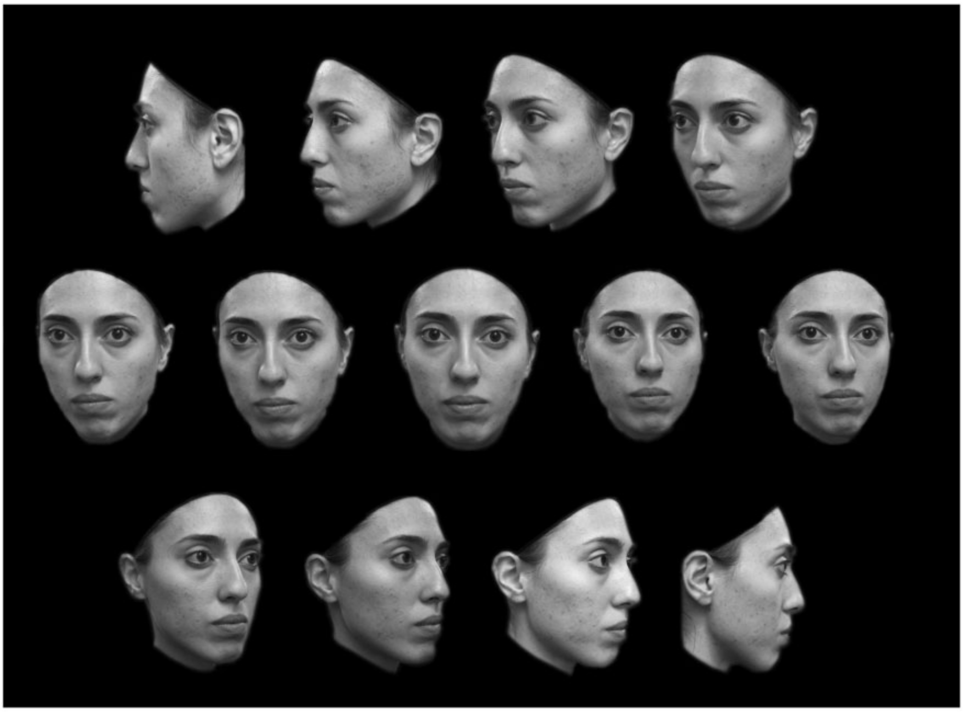

Figure 1. Examples of the stimulus displays. The top (90°, 60°, 45°, 30°) and bottom (−30°, −45°, −60°, −90°) panels show the images of an unfamiliar (unfam) face used in the familiarization phase of the experiments. In the familiarization phase the frontal view was also shown. The images in the middle panel (6°, 3°, 0°, −3°, −6°) show the stimuli used in the test phase of the experiments.

Table 1. Plan of the experiments.

Experiment 1 Familiarized or unfamiliar adaptor		**Experiment 2a** Self-face adaptor		**Experiment 2b** Familiarized or personally familiar test faces	
Adaptor	Test	Adaptor	Test	Adaptor	Test
Familiarized	Familiarized	Self-face	Familiarized	Unfamiliar	Familiarized
Familiarized	Self-face	Self-face	Unfamiliar	Unfamiliar	Friend's face
Unfamiliar	Unfamiliar				
Unfamiliar	Self-face				

Familiarization phase. Prior to the test phase, participants were repeatedly presented with the faces of four strangers, together with their fictional name and surname, occupation, and place of residence (see Ryu & Chaudhuri, 2006). The familiarization faces were presented sequentially in nine orientations for 1 s each (frontal view, 30°, 45°, 60°, and 90° rotation to the left or to the right relative to the frontal). The familiarization phase lasted 15 min.

After the familiarization phase, participants completed a test in which they were asked to retrieve the information associated with each of the four identities (name, surname, place of residency, and occupation). None of the participants repeated the learning phase a second time before reaching criterion retrieval performance (100% correct).

In Experiments 1 and 2a four strangers' faces served as to-be-familiarized stimuli. In Experiment 2b we used the familiarization procedure with a single stranger's face.

Test phase. Immediately after the familiarization phase, participants completed the test phase of the experiment comprising three blocks of trials, for a total of 160 trials. The stimulus location and order of presentation at test were randomized for each participant.

In Experiment 1, five different face identities were used in the test phase: four strangers' faces (the same faces used in the familiarization phase) and the participant's own face. In each trial, the adaptor and test faces were paired randomly by selecting two of the five face identities used in the experiment, with the constraint that adaptor and test faces had different identities.

Each trial of the test phase comprised the following sequence: a central fixation cross (5000 ms), an adapting face (5000 ms), a black screen (100 ms), and a test face (50 ms). In half of the trials the adaptor was oriented 30° left and in half of the trials it was oriented 30° right. The test faces were randomly chosen from five orientations (frontal; 3° and 6° left or right).

In each trial, the adapting and test faces were located at randomly chosen positions of the screen, with the constraint of a minimum distance between the outer edges of the two images of at least 4° of the visual angle. The randomization of the positions of the adapting and test stimuli had the purpose of reducing low-level retinotopic adaptations (e.g. Chen et al., 2010). For the same goal, we used different face identities for the adaptor and test stimuli.

Experiment 2a differed from Experiment 1 in that we always used the self-face as the adaptor stimulus (see Table 1). In the test phase we used the images of four strangers' faces.

Experiment 2b differed from Experiment 1 in two ways: the images of four (rather than five) strangers' faces were used as adaptor stimuli and, in the test phase, we used either the face of a close friend of the participant, or the face of a single stranger (see Table 1). The friend was matched in gender and age with the participant. The stranger's face used in the test phase differed from the strangers' faces used as adaptor stimuli.

Each participant was tested individually. Before performing the experiment, participants completed a short practice session (12 trials) in order to familiarize themselves with the procedure used in the experiment.

Data analysis

In order to compute the transfer of the face viewpoint aftereffect from adaptation, the participants' responses were coded as indicating whether the test image was perceived as facing away from the adaptor or not. To quantify the magnitude of the viewpoint aftereffect, psychometric functions were fit to each experimental condition by using a cumulative normal function. Generalized mixed-effects models with binomial error structure and a probit link function were used to analyse the participants' binary responses (facing away from the adaptor or not) by using the procedure described by Bates, Kliegl, Vasishth, and Baayen (2015); see also Caudek (2013). The RTs were analysed by using linear mixed-effects models. The analyses were performed using the `lme4` package (Bates, Mächler, Bolker, & Walker, 2015) for the `R` statistical environment (version 3.2.2, R Core Team, 2015). For both types of analyses, we determined the significant random and fixed effects by first building a model (estimated through maximum likelihood) with the maximal random-effect structure (Barr, Levy, Scheepers, & Tily, 2013). In a step-wise procedure, we then removed single random effects to create reduced models. The reduced models were tested against the more complex models by a log-likelihood ratio test (Baayen, Davidson, & Bates, 2008) to identify the random effects to be retained in the model. The significance of the fixed effects was tested by analysing the deviance of nested models by using a Type III analysis of deviance as implemented in the package `car` (Fox & Weisberg, 2010). Post hoc multiple comparisons were performed by means of the functions in the package `multcomp` to ensure that the overall type I error remained below the significance level $\alpha = 0.05$ (Hothorn, Bretz, & Westfall, 2008).

RTs below 200 ms were removed. The remaining RTs were log-transformed to approximate a normal distribution. Log-transformed outlier RTs were cut off at a value three times the interquartile range above the third quartile and below the first quartile (Tukey, 1977). Using this procedure, 2.9% of outlier RT observations were discarded.

Experiment 1

From the familiarity levels presently considered (never-before-seen faces, recently familiarized faces, personally familiar faces, and the participant's own face), in Experiment 1 we selected as the adaptor either a wholly unfamiliar face or a recently familiarized face. For the test we used a recently familiarized face, an unfamiliar face, or the participant's own face.

Design

In each trial of the experiment, we considered four different pairings between the familiarity levels of the adaptor and test faces: a familiarized adaptor (i.e. an adaptor face image initially unfamiliar to the participants, with which participants were familiarized in the learning phase of the experiment) together with a familiarized test face (`fam_fam`), a familiarized adaptor together with the self-face as the test image (`fam_self`), an unfamiliar (i.e. never-before-seen) adaptor together with the self-face as the test image (`unfam_self`), and an unfamiliar adaptor together with an unfamiliar test face (`unfam_unfam`). Half of the participants underwent a familiarization phase prior to the experiment whereas the other half did not. Each test session consisted of 160 trials: 120 presentations of either the `unfam_unfam` or the `fam_fam` conditions, and 40 presentations of either the `unfam_self` or the `fam_self` conditions, both divided equally between right and left adapting orientations. In the baseline condition, a separate group of participants completed the test phase with neither adaptation, nor with any prior familiarization phase.

Participants

Twelve subjects (nine females, aged 23–32 years; mean age: 25.8 years) participated voluntarily in Experiment 1. An additional four subjects participated voluntarily in the baseline condition (two females, aged 24–25 years; mean age: 24.3 years). All participants were right-handed, Caucasian, and had normal or corrected-to-normal vision. The participants were naïve to the purpose of the study and none of them had previously been exposed to the stimuli used. The experiment was undertaken with the understanding and written consent of each participant. The experiment conformed to the institutional and national guidelines for experiments with human subjects and was run in accordance with the Declaration of Helsinki.

Results

In the baseline condition, participants were asked to decide whether the test face was oriented left or right (relative to the head-on position), in the absence of any adaptation. The results were estimated through a psychometric function with the proportions of 'faces oriented right' expressed as a function of the actual viewing angles of the faces. In these circumstances, the participants' responses showed no bias: The estimated point of subjective equality (PSE) was equal to 0.03°, 95% bootstrap confidence interval (CI) [−0.64°, 0.69°]. However, following a 5 s adaptation to the 30° side views of the adapting faces, participants' judgements of the orientation of the face test images changed and were generally shifted to the opposite direction from the adapted face orientation (`fam_fam`: 1.47°; `fam_self`: 1.35°; `unfam_unfam`: 0.68°; `unfam_self`: 0.01°).

A generalized mixed-effects model with a probit link function was adapted to the participants' raw responses (coded as indicating whether the test image was perceived as facing away from the adaptor or not), with random intercepts for each participant/condition cluster and random slopes for each participant. The interaction test orientation × adaptor-test familiarity' (with the following levels for adaptor-test familiarity: `fam_fam`, `fam_self`, `unfam_unfam`, `unfam_self`) was not significant, $\chi^2_3 = 1.88$, $p = .5976$, providing no evidence that the slopes of the psychometric functions differed across conditions. The effect of test orientation was significant, $\chi^2_1 = 144.10$, $p = .0001$. Importantly, the effect of adaptor-test familiarity was significant, $\chi^2_3 = 10.67$, $p = .0136$. An overview of the effect sizes for Experiment 1 is reported in Figure 2.[1]

The PSE in the `fam_self` condition was not statistically different from the PSE in the `fam_fam` condition, $z = -0.73$, $p = .4638$ (see Figure 2). The PSE for the `fam_fam` condition corresponded to a statistically significant shift of 1.47° of the perceived face orientation in the

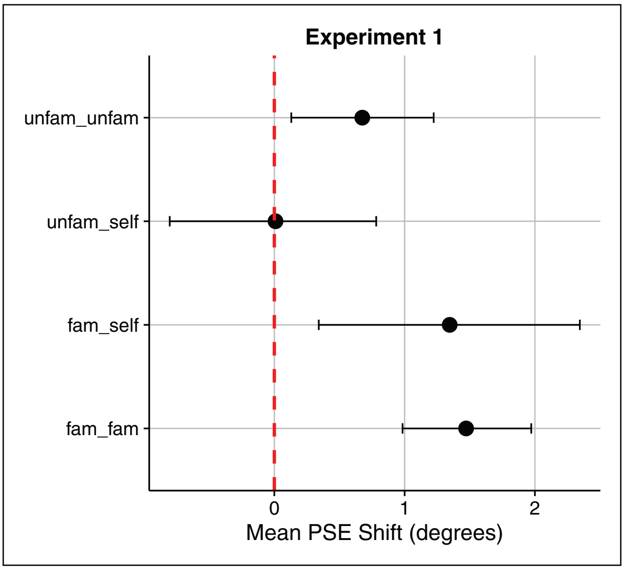

Figure 2. Shifts of the PSEs in Experiment 1. Positive values indicate viewpoint aftereffects in the expected direction, that is, shifts in a direction opposite that of the adapting orientation (repulsive aftereffects). Error bars indicate bootstrap 95% CIs. Note that the 95% CI of the `unfam_self` condition does include the zero point, indicating a not statistically significant aftereffect.

direction opposite that of the adaptor, bootstrap 95% CI: [0.984°, 1.97°]. The PSE for the `fam_self` condition corresponded to a statistically significant shift of 1.35° of the perceived face orientation in the direction opposite that of the adaptor, bootstrap 95% CI: [0.34°, 2.35°]. The shift of the PSE in the `unfam_unfam` condition was smaller than the shift of the PSE in the `fam_fam` condition, $z = -2.50$, $p = .0123$. The PSE for the `unfam_unfam` condition corresponded to a statistically significant shift of 0.68° of the perceived face orientation in the direction opposite that of the adaptor, bootstrap 95% CI: [0.13°, 1.22°]. Importantly, there was no statistically significant shift in the PSE in the `unfam_self` condition. In the `unfam_self` condition, the PSE was equal to 0.01°, not statistically different from zero, bootstrap 95% CI: [−0.80°, 0.78°].

The odds ratio (the ratio of the odds for $x = 1$ to the odds for $x = 0$) provides a measure of the effect size. By using the treatment (dummy) coding for the four pairings between the familiarity level of the adaptor and test faces, with `unfam_self` as the base reference level, the odd ratios estimated by the mixed-effect model were equal to 1.77, 1.50, and 1.25 for the `fam_fam`, `fam_self`, and `unfam_unfam` conditions, respectively.

Confidence intervals were also computed for Tukey's all-pairwise differences among the four adaptor-test familiarity levels by means of the procedure implemented in the `multcomp` package.[2] As indicated in Figure 3, the transfer of adaptation from an unfamiliar face to the self-face was smaller than the transfer of adaptation from a familiarized adaptor to a familiarized test. Moreover, the transfer of adaptation from an unfamiliar adaptor to an unfamiliar test was smaller than the transfer of adaptation from a familiarized adaptor to a familiarized test. No other pairwise comparisons were statistically significant.

By considering only the `unfam_self` and the `fam_self` conditions, we run again the mixed-effect model described above by adding to the fixed effects part of the model the

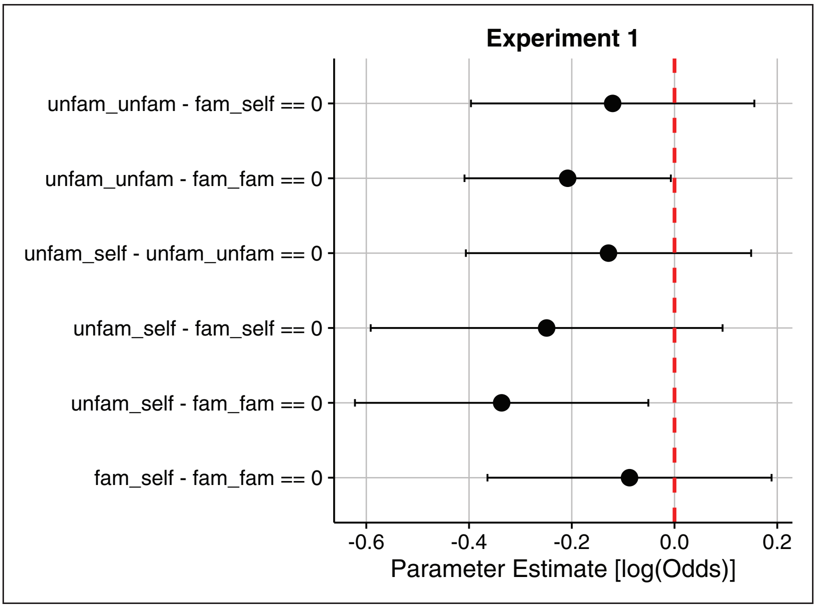

Figure 3. Tukey's all-pairwise differences estimated in the logit mixed-effects model for Experiment 1. Error bars represent 95% CIs. Note that the 95% CIs do not include zero only when comparing the `unfam_unfam` and the `fam_fam` conditions, and when comparing the `unfam_self` and the `fam_fam` conditions (a CI not including zero indicates a significant difference between the magnitudes of the viewpoint aftereffects).

participants' gender and the interactions 'gender × viewing angle' and 'gender × adaptor-test familiarity'. Neither the main effect of gender nor any of the interactions involving gender were statistically significant, $\chi^2_4 = 3.73$, $p = .4433$.

We also compared the unfam_unfam, fam_self, and fam_fam conditions, with the unfam_self condition, in order to estimate the standardized effect size for the mean difference of the PSE shifts. According to Cohen's *d* index, the effect size was medium ($d = 0.74$) for the unfam_unfam versus unfam_self comparison, large ($d = 0.83$) for the fam_self versus unfam_self comparison, and also large ($d = 0.86$) for the fam_fam versus unfam_self comparison.

Discussion

The viewpoint aftereffect was stronger in the fam_fam and fam_self conditions, was weaker in the unfam_unfam condition, and was absent in the unfam_self condition. The first two results are consistent with Hypothesis 2. Instead, the result of the unfam_self condition is consistent with Hypothesis 3.

It is interesting to compare the results of conditions unfam_self and fam_self. The only difference between these two conditions concerns the familiarization phase that was used in condition fam_self. A very short learning phase prior to the experiment was sufficient to produce a viewpoint aftereffect in the fam_self condition (which was absent in the unfam_self condition), with a magnitude comparable to that found in the fam_fam condition. This result is hardly consistent with Hypothesis 3 and highlights the dramatic plasticity of face processing as a consequence of even a very short amount of learning.

It is also important to note that the modulation of the adaptation transfer in the different conditions of Experiment 1 cannot be reduced to the image similarity between the adapting and test stimuli. In fact, the cross-identity random pairing of the adapting and test stimuli guarantees that, on average, face similarity did not vary in a systematic manner across conditions.

Experiment 2

In Experiment 2, we varied the familiarity level of the adaptor and test faces as follows. In Experiment 2a the adaptor was the participant's own face and the test was either a familiarized face or an unfamiliar face. In Experiment 2b, the adaptor was an unfamiliar face and the test face was either a familiarized face or a highly familiar face (the face of a close friend).

Participants

Twelve subjects (seven females, aged 22–29 years; mean age: 25.6 years) participated voluntarily in Experiment 2a. Another 16 subjects (10 females, aged 23–32 years; mean age: 24.9 years) participated voluntarily in Experiment 2b. All participants were right-handed, Caucasian, and had normal or corrected-to-normal vision. The participants were naïve to the purpose of the study and none of them had participated in Experiment 1 or previously been exposed to the stimuli used. The experiment was undertaken with the understanding and written consent of each participant. The experiment conformed to the institutional and national guidelines for experiments with human subjects and was run in accordance with the Declaration of Helsinki.

Design

In Experiment 2a there were two between-subjects pairings between the familiarity levels of the adaptor and test faces: self-face adaptor and unfamiliar test (`self_unfam`) or self-face adaptor and familiarized test (`self_fam`). In Experiment 2b there were two between-subjects pairings between the familiarity levels of the adaptor and test faces: unfamiliar adaptor and familiarized test (`unfam_fam`) or unfamiliar adaptor and friend's face test (`unfam_friend`).

In Experiment 2a, each session consisted of 160 trials, either in the `self_unfam` or in the `self_fam` conditions, both divided equally between right and left adapting orientations. In Experiment 2b, each session consisted of 160 trials, either in the `unfam_fam` or in the `unfam_friend` conditions, both divided equally between right and left adapting orientations.

Results

Experiment 2a. A generalized mixed-effects model with a probit link function was adapted to the participants' raw responses (coded as in Experiment 1), with random intercepts and random slopes for each participant. The interaction 'test orientation × adaptor-test familiarity' (with the following levels for adaptor-test familiarity: `self_unfam`, `self_fam`) was not significant, $\chi^2_1 = 0.16$, $p = .6909$, providing no evidence that the slopes of the psychometric functions differed across conditions. The effect of test orientation was significant, $\chi^2_1 = 105.79$, $p = .0001$, but the effect of the pairing between the familiarity levels of adaptor and test faces was not, $\chi^2_1 = 1.02$, $p = .3115$. No statistically significant effects were found for the participants' gender, nor for any interactions involving gender, $\chi^2_4 = 6.94$, $p = .1394$.

The PSE for the `self_unfam` condition corresponded to a statistically significant shift of 0.76° of the perceived face orientation in the direction opposite that of the adaptor, bootstrap 95% CI: [0.34°, 1.18°] (see Figure 4). Also, the `self_fam` condition produced a statistically

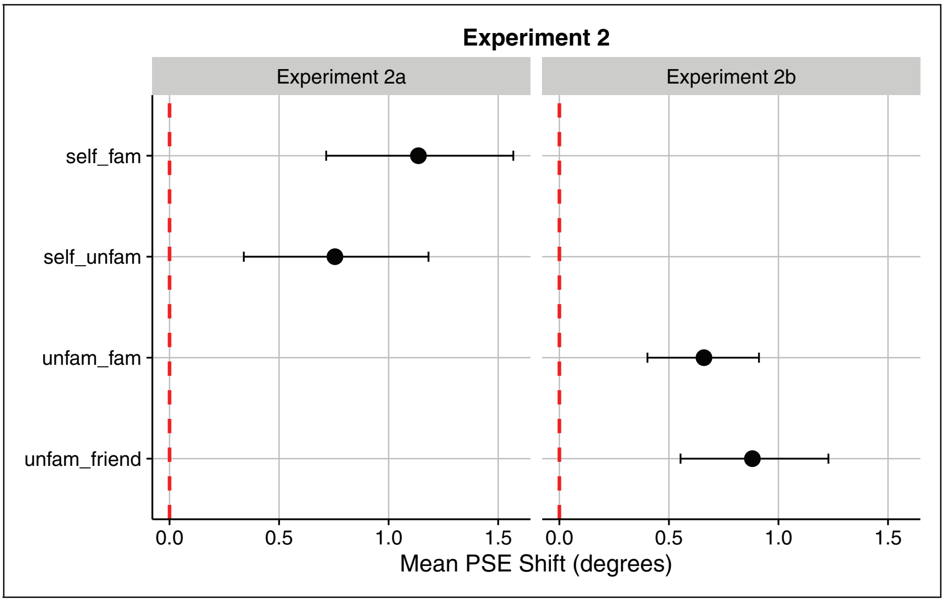

Figure 4. Shifts of the PSEs in Experiment 2. Positive values indicate viewpoint aftereffects in the expected direction (repulsive aftereffects). Error bars indicate bootstrap 95% CIs.

significant shift of the perceived face orientation in the direction opposite that of the adaptor, PSE = 1.14°, bootstrap 95% CI: [0.72°, 1.57°].

Experiment 2b. A similar analysis performed for the data of Experiment 2b showed that the interaction 'test orientation × adaptor-test familiarity' (with the following levels for adaptor-test familiarity: `unfam_fam`, `unfam_friend`) was not statistically significant, $\chi^2_1 = 0.01$, $p = .9471$. The effect of test orientation was statistically significant, $\chi^2_1 = 93.71$, $p = .0001$, but the effect of the pairing between the familiarity levels of the adaptor and test faces was not, $\chi^2_1 = 0.61$, $p = .4354$.

In the `unfam_fam` condition, the PSE corresponded to a statistically significant shift of 0.66° of the perceived face orientation in the direction opposite that of the adaptor, bootstrap 95% CI: [0.40°, 0.91°]. Also, the `unfam_friend` condition produced a statistically significant shift of perceived face orientation in the direction opposite that of the adaptor, PSE = 0.88°, bootstrap 95% CI: [0.55°, 1.23°].

Effect of unfamiliar adaptors (Experiments 1 and 2b). In Experiment 1, an unfamiliar adaptor was paired with an unfamiliar test face and with the self-face; in Experiment 2b, an unfamiliar adaptor was paired with the image of a friend's face and with the image of a familiarized face. By following the procedure described in Experiment 1, we compared the amount of adaptation transfer when the test face was the participant's face with the amount of adaptation transfer when the test face had different levels of familiarity (an unfamiliar face, a familiarized face, and a personally familiar face). The results of these three pairwise comparisons are shown in Table 2 (unidirectional tests). As expected, the transfer of the adaptation from an unfamiliar face to the self-face was significantly smaller than the transfer of adaptation from an unfamiliar adaptor to a personally familiar face (friend's face). The transfer of the adaptation from an unfamiliar adaptor to the self-face was also significantly smaller than that observed when using a familiarized test face. The third comparison, instead, which involves in the test phase either an unfamiliar face or the self-face, was not statistically significant.

We also estimated the standardized effect size for the mean difference of the PSE shifts by comparing the adaptor-test familiarity levels of Experiments 2a and 2b with the `nonfam_self` condition of Experiment 1. The effect size was large (Cohen's $d = 1.32$) for the `self_fam` versus `unfam_self` comparison and it was also large ($d = 0.90$) for the `self_unfam` versus `unfam_self` comparison; the effect size was medium ($d = 0.52$) for the `unfam_fam` versus `unfam_self` comparison and it was large ($d = 1.22$) for the `unfam_friend` versus `unfam_self` comparison.

Discussion

The results of Experiment 2a indicate that the self-face generates a transfer of the viewpoint adaptation comparable to that produced by a face which has been familiarized by means of a

Table 2. Pairwise comparisons (on the logit scale) among the experimental conditions which include an unfamiliar adaptor for the combined data of Experiments 1 and 2.

	Estimate	Standard error	z value	*Pr*(> z)
unfam_unfam - unfam_self ≤ 0	0.12	0.11	1.03	.2738
unfam_friend - unfam_self ≤ 0	0.30	0.13	2.30	.0256
unfam_fam - unfam_self ≤ 0	0.29	0.13	2.27	.0275

very short learning phase. Moreover, the comparison between the unfam_fam condition of Experiment 2b and the unfam_self condition of Experiment 1 indicates that an unfamiliar adaptor can yield a transfer of adaptation to a familiar face, but not to the self-face. Finally, an unfamiliar adaptor (Experiment 2b) yielded a magnitude of transfer of adaptation to a personally familiar face (a friend's face) that was comparable to that found when a familiarized face was used as the test stimulus (with a level of familiarity artificially generated in the laboratory with a brief learning session).

Analysis of the RTs

The RTs of all experiments were analysed with a mixed-effects model with the amount of rotation from the frontal position of the test face (0°, 3°, 6°), the familiarity level of the adaptor (familiar, unfamiliar), the familiarity level of the test image (familiar, unfamiliar), and the adaptor familiarity × test familiarity interaction as fixed effects. The final model comprised by-subject random intercepts and by-subject random slopes for the amount of rotation from the frontal position of the test image. By following the procedure suggested by Baayen and Milin (2010), we removed data points with absolute standardized residuals exceeding 2.5 standard deviations (1.5% of the total) and refitted the model. The results indicate that the mean log(RT) decreased as a function of the amount of rotation from the frontal position, $\chi^2_1 = 30.81$, $p = .0001$. Interestingly, participants' latencies of response were about 733 ms longer when the test stimulus was an unfamiliar rather than a personally familiar or familiarized face, $\chi^2_1 = 5.78$, $p = .0162$. However, such different uncertainty in the responses was not associated with any uncontrolled difference in viewing times across conditions because the test stimulus was only presented for 50 ms. None of the other main effects or interactions were statistically significant.

General discussion

Our study confirms previous findings showing that visual representations of different kinds of faces (the participant's own face, unfamiliar, familiar, and personally familiar faces) undergo rapid adaptation. The novel result of our experiments is to show that the cross-identity face viewpoint aftereffect varies as a function of the degree of familiarity and that, in specific circumstances, the self-face is processed differently than a personally familiar face (friend), an artificially familiarized face, or an unfamiliar face.

We found a similar viewpoint aftereffect when the test stimulus was the self-face and when the adaptor was a familiarized face (self_fam), or vice versa (fam_self). This symmetry between the effects of the level of familiarity of the adaptor and the test stimuli, however, was absent for the pairing between the self-face and an unfamiliar face image: we found adaptation transfer between the self-face adaptor and an unfamiliar test face (self_unfam) but no transfer of adaptation towards the self-face when the adaptor was an unfamiliar face (unfam_self).

Fang et al. (2007) suggest that the magnitude of the transfer of the viewpoint aftereffect between different stimuli is proportional to the overlap of their neural representations. Accordingly, the present results indicate that the greatest 'neural distance' is found between an unfamiliar adaptor and the self-face test.

Importantly, the comparison between the unfam_self and the fam_self conditions shows that a very short familiarization phase with an initially unfamiliar face is sufficient to yield a transfer of adaptation towards the self-face (unfam_self). In Experiment 1, in fact, the unfam_self and the fam_self conditions only differed for the presence of a short familiarization phase. The difference between the results obtained in the unfam_self and fam_self conditions thus highlights the great plasticity of the visual system for what concerns the processing of the self-face.

The present results are inconsistent with Hypothesis 1 in 'Introduction'. In fact, we found a similar viewpoint aftereffect in the fam_fam and self-fam conditions, although Hypothesis 1 predicts a much smaller viewpoint aftereffect in the second case. Our results are also, at least in part, inconsistent with Hypothesis 2. We found a large difference in the viewpoint aftereffect between the unfam_fam and unfam_self conditions, with no aftereffect in the latter case, although Hypothesis 2 predicts the opposite result. In fact, the degree of familiarity that we created in the laboratory is certainly smaller than the degree of familiarity that is naturally associated with the self-face. Therefore, Hypothesis 2 must be emended in order to take into consideration not only the amount of familiarity but also the specificity of the self-face with respect to other highly familiar faces. Finally, the present results are also inconsistent with Hypothesis 3, because we found a viewpoint aftereffect in the self_unfam, self_fam, and fam_self conditions, where the self-face served either as adaptor or as test stimulus, although Hypothesis 3 predicts no aftereffect in all these cases.

It is interesting to compare the size of the viewpoint aftereffect when familiarity was artificially induced in the laboratory and when familiarity was produced in an ecological context by the prior social experience of the participants (e.g. the face of a friend). The transfer of adaptation in the unfam_unfam condition was very similar to that found in the unfam_friend condition. This suggests that an unfamiliar face can act as an efficient adaptor both with an unfamiliar test face and with a personally familiar test face. Moreover, the comparison of the fam_fam and the unfam_fam conditions suggests that, when the degree of familiarity of the test stimulus is kept constant (a face artificially familiarized in the laboratory), a greater level of familiarity with the adaptor strengthens the transfer of the cross-identity viewpoint aftereffect, consistent with Hypothesis 2.

Walton and Hills (2012) have suggested that, when adaptation is studied by using distorted faces, extremely familiar faces may resist the aftereffects following adaptation because 'participants [...] know that those faces can never be distorted in that way' (p. 6). In fact, they found a very small aftereffect when using personally familiar faces as test stimuli. Such an argument, however, does not apply to the viewpoint aftereffect because, within such a paradigm, face distortions are never present.

We can relate the present results to the neuro-physiological literature in which several recent studies have examined the possibility that unfamiliar faces, familiar faces, and the self-face may be processed by different neural substrates, with a different hemispheric specialization. Although the locus of the aftereffect may be distributed across multiple levels of the visual hierarchy (Zimmer & Kovacs, 2011), there are indications that the self-face, on the one side, and unfamiliar faces, on the other, may elicit preferential responses in different brain regions. For example, Taylor et al. (2009) found that the processing of unfamiliar faces appears to recruit primarily the left hemisphere (see also Eger et al., 2005); conversely, the processing of the self-face seems to be mainly supported by the right hemisphere (Keenan, Nelson, O'Connor, & Pascual-Leone, 2001). Given that these two classes of faces are predominantly processed by different hemispheres, adaptation to one of these classes of faces should not produce a transfer of the viewpoint aftereffect to the other class of faces. However, the present data cannot be fully explained by the hypothesis of a hemispheric specialization of the processing of faces having different levels of familiarity. In fact, although we did not find a transfer of adaptation from an unfamiliar face to the self-face (unfam_self), we did find an adaptation transfer from the self-face to an unfamiliar face (self_unfam).

Overall, we consider the present results to be compatible with the hypothesis that familiarity strengthens the viewpoint aftereffect, albeit with a caveat. Hypothesis 2 rests on the idea of a collection of neural populations in the human visual system, each tuned to a particular view. Familiarity (i.e. learning) may sharpen the orientation tuning curve for each view (e.g. Moldakarimov, Bazhenov, & Sejnowski, 2014) and this may favour the transfer of adaptation (see the comparison between the `fam_fam` and the `unfam_unfam` conditions). The caveat is that the self-face cannot be considered solely as an over-learned face because, differently from a personally familiar face (`unfam_friend`), it resists the transfer of adaptation from a 'weak' (unfamiliar) adaptor (`unfam_self`). This suggests that the self-face may be coded in a different manner than other kinds of faces, given that we always found a transfer of adaptation among unfamiliar faces, familiarized faces, and personally familiar faces. However, the 'robustness' of the self-face disappeared after a very short familiarization with the adaptor stimulus (`fam_self` condition). Moreover, no differences in the magnitude of the viewpoint aftereffect were found between the `self_fam` and the `fam_fam` conditions, or between the `self_unfam` and the `unfam_unfam` conditions, which suggests that the participant's own face reveals no specificity when it is used as the adaptor with respect to familiar or unfamiliar faces used as a test (contrary to Hypothesis 1).

Laurence and Hole (2011) examined the within-identity transfer of adaptation with distorted faces and found smaller aftereffects when participants were adapted to their own face than when they were adapted to another person's face. One possible explanations of this 'own-face' effect was formulated in terms of Valentine's (1991) multidimensional face space model. Within this framework, Laurence and Hole proposed that the 'own-face' effect could be due to the fact that the centre of each individual's personal face-space may be based on his/her own face. If this were true, however, in the present case we would expect a smaller viewpoint aftereffect in the `self_fam` condition than in the `fam_fam` condition, and a smaller viewpoint aftereffect in the `self_unfam` condition than in the `unfam_unfam` condition. Neither of these two predictions is supported by the present data. The present results, therefore, do not support the hypothesis that the self-face might be used as the centre of each individual's personal face-space.

Walton and Hills (2012) have suggested that personally familiar faces may not be stored in the face-space, but rather as unique entities. This idea could be extended to the representation of the self-face (Hypothesis 3). Although such a proposal is consistent with the data of the `unfam_self` condition, it does not explain the results of all the other conditions of the present study in which the self-face was used either as the adaptor or as the test stimulus.

No statistically significant difference in discrimination performance depending on the pairing between the familiarity levels of the adaptor and test faces was found in any of the three experiments (Experiment 1: familiarized or unfamiliar adaptor; Experiment 2a: self-face adaptor; Experiment 2b: familiarized or personally familiar test). It must be considered, however, that the modulation of discrimination performance in adaptation studies is proportional to the length of the visual experience. Many studies have shown that perceptual learning requires tens of hours of training, often over an extended period of time (e.g. Lorenzino & Caudek, 2015). In the current study, however, the familiarization phase was only 15 min. Such a short training was capable of modulating the size of the viewpoint aftereffect, but it did not affect discrimination accuracy.

A question that the present study has not answered is whether the long-term stability of the face adaptation effects is modulated by the level of familiarity. For example, Ditye et al. (2013) adapted participants to images of famous actors and then measured the perceived distortion levels either after a full night's sleep or after a 90 min nap. Control groups remained awake during the same time intervals and were blindfolded to prevent visual input. Interestingly, Ditye et al. found that participants who slept exhibited a stronger aftereffect than those who remained awake. This indicates that sleep prevents decay of adaptation and favours memory consolidation also for complex visual representations, such as faces. Whether such consolidation depending on sleep operates differently for the self-face and for other real-world familiar faces remains an interesting question for future research.

To conclude, the present results provide new insights into the face viewpoint adaptation. The different magnitudes of the viewpoint aftereffect as a function of the level of familiarity suggest that face view-selective neurons in the human visual system may be also tuned to face familiarity (Rooney et al., 2012; Walton & Hills, 2012). Such results are consistent with the idea that face coding is not only view-specific (Fang, Ijichi, & He, 2007; Jeffery, Rhodes, & Busey, 2006) but also identity-specific. Moreover, the demonstration that the self-face can modulate the viewpoint aftereffect in a different manner than the level of familiarity (generated artificially in the laboratory or generated through the experience in a social context) suggests that separate cell populations may encode face viewpoint in the case of highly familiar faces and in the case of the self-face. The findings indicating that (1) the self-face was the only stimulus capable of resisting the adaptation transfer from a 'weak' adaptor, and (2) the transfer of adaptation to the self-face was affected by the familiarization with the adaptor more than any other class of faces, might highlight the specificity of self-face processing. These results are interesting because they are not easily accommodated within the current models of face processing.

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Notes

1. The magnitude of the face viewpoint aftereffects that we found is comparable to what had been reported by Fang et al. (2007) in a similar experiment. Fang et al. found that the effect size of the aftereffect decreased as the adapting and the test stimuli became more and more dissimilar. In their case, the size of the aftereffect decreased from 2.1° for same-identity adaptor-test faces to 1.6° for the most dissimilar adaptor and test pairings. For a 30° adaptor and same-identity adaptor-test faces, Chen et al. (2010) reported an aftereffect of 2.2°. Similar results had been obtained by Balas and Valente (2012) with an adaptor pose of 20° and same-identity adaptor-test faces.
2. These pairwise differences, derived from the predictions of the mixed-effects model described above, are computed on the logit scale (i.e. $\log[p/(1p)]$ or log odds ratio). A positive difference between two such values indicates that the first p is greater than the second p. By exponentiating these estimated differences, ratios of odds ratios are obtained.

References

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, *59*, 390–412.

Baayen, R. H., & Milin, P. (2010). Analyzing reaction times. *International Journal of Psychological Research*, *3*, 12–28.

Balas, B., & Valente, N. (2012). View-adaptation reveals coding of face pose along image, not object, axes. *Vision Research*, *67*, 22–27.

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, *68*, 255–278.

Bates, D., Kliegl, R., Vasishth, S., & Baayen, H. (2015). Parsimonious mixed models. *Submitted on 16 June 2015 to Journal of Memory and Language*. arXiv preprint arXiv:1506.04967.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*, 1–48.

Bi, T., Su, J., Chen, J., & Fang, F. (2009). The role of gaze direction in face viewpoint aftereffect. *Vision Research*, *49*, 2322–2327.

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision*, *10*, 433–436.

Bruce, V. (1982). Changing faces: Visual and non-visual coding processes in face recognition. *British Journal of Psychology*, *73*, 105–116.

Burton, A. M., Wilson, S., Cowan, M., & Bruce, V. (1999). Face recognition in poor-quality video: Evidence from security surveillance. *Psychological Science*, *10*, 243–248.

Butler, A., Oruc, I., Fox, C. J., & Barton, J. J. S. (2008). Factors contributing to the adaptation aftereffects of facial expression. *Brain Research*, *1191*, 116–126.

Caharel, S., Jacques, C., d'Arripe, O., Ramon, M., & Rossion, B. (2011). Early electrophysiological correlates of adaptation to personally familiar and unfamiliar faces across viewpoint changes. *Brain Research*, *1387*, 85–98.

Carbon, C.-C. (2008). Famous faces as icons. The illusion of being an expert in the recognition of famous faces. *Perception*, *37*, 801–806.

Carbon, C.-C., & Ditye, T. (2011). Sustained effects of adaptation on the perception of familiar faces. *Journal of Experimental Psychology: Human Perception and Performance*, *37*, 615–625.

Carbon, C.-C., & Ditye, T. (2012). Face adaptation effects show strong and long-lasting transfer from lab to more ecological contexts. *Frontiers in Psychology*, *3*, 3.

Carbon, C.-C., & Leder, H. (2005). Face adaptation: Changing stable representations of familiar faces within minutes? *Advances in Experimental Psychology*, *1*, 1–7.

Carbon, C.-C., & Leder, H. (2006). The Mona Lisa effect: Is 'our' Lisa fame or fake? *Perception*, *35*, 411–414.

Carbon, C.-C., Strobach, T., Langton, S. R. H., Harsanyi, G., Leder, H., & Kovacs, G. (2007). Adaptation effects of highly familiar faces: Immediate and long lasting. *Memory and Cognition*, *35*, 1966–1976.

Caudek, C. (2013). The fidelity of visual memory for faces and non-face objects. *Acta Psychologica*, *143*, 40–51.

Caudek, C., & Monni, A. (2013). Do you remember your sad face? The roles of negative cognitive style and sad mood. *Memory*, *21*, 891–903.

Chen, J., Yang, H., Wang, A., & Fang, F. (2010). Perceptual consequences of face viewpoint adaptation: Face viewpoint aftereffect, changes of differential sensitivity to face view, and their relationship. *Journal of Vision*, *10*, 1–11.

Clifford, C. W., Webster, M. A., Stanley, G. B., Stocker, A. A., Kohn, A., Sharpee, T. O., . . . Schwartz, O. (2007). Visual adaptation: Neural, psychological and computational aspects. *Vision Research*, *47*, 3125–3131.

Daar, M., & Wilson, H. R. (2012). The face viewpoint aftereffect: Adapting to full faces, head outlines, and features. *Vision Research*, *53*, 54–59.

Dalton, P. (1993). The role of stimulus familiarity in context-dependent recognition. *Memory & Cognition*, *21*, 223–234.

Devue, C., & Brédart, S. (2008). Attention to self-referential stimuli: Can I ignore my own face? *Acta Psychologica*, *128*, 290–297.
Ditye, T., Javadi, A. H., Carbon, C. C., & Walsh, V. (2013). Sleep facilitates long-term face adaptation. *Proceedings of the Royal Society of London B: Biological Sciences*, *280*, 20131698.
Duarte, A., Ranganath, C., Winward, L., Hayward, D., & Knight, R. T. (2004). Dissociable neural correlates for familiarity and recollection during the encoding and retrieval of pictures. *Cognitive Brain Research*, *18*, 255–272.
Eger, E., Schweinberger, S. R., Dolan, R. J., & Henson, R. N. (2005). Familiarity enhances invariance of face representations in human ventral visual cortex: fMRI evidence. *Neuroimage*, *26*, 1128–1139.
Fang, F., & He, S. (2005). Viewer-centered object representation in the human visual system revealed by viewpoint aftereffects. *Neuron*, *45*, 793–800.
Fang, F., Ijichi, K., & He, S. (2007). Transfer of the face viewpoint aftereffect from adaptation to different and inverted faces. *Journal of Vision*, *7*, 1–9.
Fox, J., & Weisberg, S. (2010). *An R companion to applied regression*. Thousand Oaks, CA: SAGE.
Gillihan, S. J., & Farah, M. J. (2005). Is self special? A critical review of evidence from experimental psychology and cognitive neuroscience. *Psychological Bulletin*, *131*, 76–97.
Gobbini, M. I., Gors, J. D., Halchenko, Y. O., Rogers, C., Guntupalli, J. S., Hughes, H., . . . Cipolli, C. (2013). Prioritized detection of personally familiar faces. *PLoS One*, *8*, e66620.
Gobbini, M. I., & Haxby, J. V. (2007). Neural systems for recognition of familiar faces. *Neuropsychologia*, *45*, 32–41.
Hills, P. J., & Lewis, M. B. (2012). FIAEs in famous faces are mediated by type of processing. *Frontiers in Psychology*, *3*, 256.
Hothorn, T., Bretz, F., & Westfall, P. (2008). Simultaneous inference in general parametric models. *Biometrical Journal*, *50*, 346–363.
Hurlbert, A. (2001). Trading faces. *Nature Neuroscience*, *4*, 3–5.
Jeffery, L., Rhodes, G., & Busey, T. (2006). View-specific coding of face shape. *Psychological Science*, *17*, 501–505.
Jenkins, R., Beaver, J. D., & Calder, A. J. (2006). I thought you were looking at me – Direction-specific aftereffects in gaze perception. *Psychological Science*, *17*, 506–513.
Jiang, F., Blanz, V., & O'Toole, A. J. (2007). The role of familiarity in three-dimensional view-transferability of face identity adaptation. *Vision Research*, *47*, 525–531.
Jiang, F., Blanz, V., & O'Toole, A. J. (2009). Three-dimensional information in face representations revealed by identity aftereffects. *Psychological Science*, *20*, 318–325.
Jin, D. Z., Dragoi, V., Sur, M., & Seung, H. S. (2005). Tilt aftereffect and adaptation-induced changes in orientation tuning in visual cortex. *Journal of Neurophysiology*, *94*, 4038–4050.
Johnston, R. A., & Edmonds, A. J. (2009). Familiar and unfamiliar face recognition: A review. *Memory*, *17*, 577–596.
Jung, K., Ruthruff, E., & Gaspelin, N. (2013). Automatic identification of familiar faces. *Attention Perception & Psychophysics*, *75*, 1438–1450.
Keenan, J. P., McCutcheon, B., Freund, S., Gallup, G. G., Sanders, G., & Pascual-Leone, A. (1999). Left hand advantage in a self-face recognition task. *Neuropsychologia*, *37*, 1421–1425.
Keenan, J. P., Nelson, A., O'Connor, M., & Pascual-Leone, A. (2001). Self-recognition and the right hemisphere. *Nature*, *409*, 305.
Keyes, H., & Dlugokencka, A. (2014). Do I have my attention? Speed of processing advantages for the self-face are not driven by automatic attention capture. *PLoS ONE*, *9*, e110792.
Kircher, T. T., Senior, C., Phillips, M. L., Rabe-Hesketh, S., Benson, P. J., Bullmore, E. T., , . . . David, A. S. (2001). Recognizing one's own face. *Cognition*, *78*, B1–B15.
Laurence, S., & Hole, G. (2011). The effect of familiarity on face adaptation. *Perception*, *40*, 450–463.
Leopold, D. A., O'Toole, A. J., Vetter, T., & Blanz, V. (2001). Prototype-referenced shape encoding revealed by high-level aftereffects. *Nature Neuroscience*, *4*, 89–94.
Leopold, D. A., Rhodes, G., Müller, K. M., & Jeffery, L. (2005). The dynamics of visual adaptation to faces. *Proceedings of the Royal Society B: Biological Sciences*, *272*, 897–904.

Lorenzino, M., & Caudek, C. (2015). Task-irrelevant emotion facilitates face discrimination learning. *Vision Research*, *108*, 56–66.

Ma, Y., & Han, S. (2009). Self-face advantage is modulated by social threat – Boss effect on self-face recognition. *Journal of Experimental Social Psychology*, *45*, 1048–1051.

Ma, Y., & Han, S. (2010). Why we respond faster to the self than to others? An implicit positive association theory of self-advantage during implicit face recognition. *Journal of Experimental Psychology: Human Perception and Performance*, *36*, 619–633.

MacLin, O. H., & Webster, M. A. (2001). Influence of adaptation on the perception of distortions in natural images. *Journal of Electronic Imaging*, *10*, 100–109.

Moldakarimov, S., Bazhenov, M., & Sejnowski, T. J. (2014). Top-down inputs enhance orientation selectivity in neurons of the primary visual cortex during perceptual learning. *PLoS Computational Biology*, *10*, e1003770.

O'Toole, A. J., Edelman, S., & Bülthoff, H. H. (1998). Stimulus-specific effects in face recognition over changes in viewpoint. *Vision Research*, *38*, 2351–2363.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision*, *10*, 437–442.

Pourtois, G., Schwartz, S., Seghier, M. L., Lazeyras, F., & Vuilleumier, P. (2005). View-independent coding of face identity in frontal and temporal cortices is modulated by familiarity: An event-related fMRI study. *NeuroImage*, *24*, 1214–1224.

Rhodes, G., & Jeffery, L. (2006). Adaptive norm-based coding of facial identity. *Vision Research*, *46*, 2977–2987.

Rooney, B., Keyes, H., & Brady, N. (2012). Shared or separate mechanisms for self-face and other-face processing? Evidence from adaptation. *Frontiers in Psychology*, *3*, 1–9.

Ryu, J. J., & Chaudhuri, A. (2006). Representations of familiar and unfamiliar faces as revealed by viewpoint-aftereffects. *Vision Research*, *46*, 4059–4063.

Schwaninger, A., Carbon, C. C., & Leder, H. (2003). Expert face processing: Specialization and constraints. In G. Schwarzer, & H. Leder (Eds.), *Development of face processing* (pp. 81–97). Göttingen, Germany: Hogrefe.

Strobach, T., & Carbon, C. C. (2013). Face adaptation effects: Reviewing the impact of adapting information, time, and transfer. *Frontiers in Psychology*, *4*, 318, 1–12.

Suddendorf, T., & Butler, D. L. (2013). The nature of visual self-recognition. *Trends in Cognitive Sciences*, *17*, 121–127.

Suddendorf, T., Simcock, G., & Nielsen, M. (2007). Visual self-recognition in mirrors and live videos: Evidence for a developmental asynchrony. *Cognitive Development*, *22*, 185–196.

Sugiura, M. (2015). Three faces of self-face recognition: Potential for a multi-dimensional diagnostic tool. *Neuroscience Research*, *90*, 56–64.

Sui, J., & Han, S. (2007). Self-construal priming modulates neural substrates of self-awareness. *Psychological Science*, *18*, 861–866.

Taylor, M., Arsalidou, M., Bayless, S., Morris, D., Evans, J., & Barbeau, E. (2009). Neural correlates of personally familiar faces: Parents, partner and own faces. *Human Brain Mapping*, *30*, 2008–2020.

Tong, F., & Nakayama, K. (1999). Robust representations for faces: Evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 1016–1035.

Tukey, J. W. (1977). *Exploratory data analysis*. Reading, MA: Addison-Wesley.

Valentine, T. (1991). A unified account of the effects of distinctiveness, inversion and race in face recognition. *The Quarterly Journal of Experimental Psychology Section A*, *43*, 161–204.

Walther, C., Schweinberger, S. R., & Kovacs, G. (2013). Adaptor identity modulates adaptation effects in familiar face identification and their neural correlates. *PLoS ONE*, *8*, e70525.

Walton, B. R. P., & Hills, P. J. (2012). Face distortion aftereffects in personally familiar, famous, and unfamiliar faces. *Frontiers in Psychology*, *3*, 1–8.

Watson, T. L., & Clifford, C. W. G. (2003). Pulling faces: An investigation of the face-distortion aftereffect. *Perception*, *32*, 1109–1116.

Webster, M. A., Kaping, D., Mizokami, Y., & Duhamel, P. (2004). Adaptation to natural facial categories. *Nature*, *428*, 557–561.
Webster, M. A., & MacLin, O. H. (1999). Figural aftereffects in the perception of faces. *Psychonomic Bulletin & Review*, *6*, 647–653.
Zimmer, M., & Kovacs, G. (2011). Position specificity of adaptation-related face aftereffects. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *366*, 586–595.