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# The upper eye bias: tilted faces draw fixations to the upper eye

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# **Running Head: THE UPPER EYE BIAS**

Title: The upper eye bias: tilted faces draw fixations to the upper eye

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# Abstract

There is a consistent left gaze bias when observers fixate upright faces, but it is unknown how this bias manifests in *tilted faces*, where the two eyes appear at different heights on the face. In two eye tracking experiments, we measured participants' first and second fixations while they judged the expressions of upright and tilted faces. We hypothesized that tilted faces might elicit a bias to fixate the upper eye. Our results strongly confirmed this hypothesis, with the *upper eve bias* completely dominating the left gaze bias in  $\pm 45^{\circ}$  faces in Experiment 1, and across a range of face orientations ( $\pm 11.25^{\circ}, \pm 22.5^{\circ}, \pm 33.75^{\circ}, \pm 45^{\circ}, \pm 90^{\circ}$ ) in Experiment 2. In addition, tilted faces elicited more overall eve-directed fixations than upright faces. We consider potential mechanisms of the upper eye bias in tilted faces and discuss some implications for research in social perception and cognition. 

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# Introduction

Faces are like visual magnets, drawing our visual attention quickly, automatically, even if we attempt to avoid them (Crouzet, Kirchner, & Thorpe, 2010). Gazing at a face allows us to extract socially relevant information about a person's identity, gender, age, race, expression, and direction of gaze. In turn, the type of information we seek to gather from a face influences how we scan the face and what facial features we are most likely to fixate (Vaidya, Jin, & Fellows, 2014; Boutet, Lemieux, Goulet, & Collin, 2017). Although task, context, individual differences, and social factors can all affect our gaze behavior toward faces, there are also consistent biases found across most observers.

One of the most well-studied biases in face processing is the *left gaze bias*, in which most right-handed observers tend to fixate and attend more to the left side of the face (that is, left from the observer's perspective). First reports of a left bias in face perception were based on perceptual judgments of identity (Gilbert and Bakan, 1973) or expression (Campbell, 1978) using *chimeric* faces constructed by combining two face halves. In these studies, most observers judged "left/left" chimeric faces to be more similar to the full face than "right/right" chimeric faces. These early findings have been corroborated by two decades of eye tracking studies showing that across a variety of tasks and contexts, right-handed observers fixate more on the left side of faces (Mertens, Siegmund, & Grüsser, 1993; Butler, Gilchrist, Burt, et al., 2005; Hsiao & Cottrell, 2008; Guo, Meints, Hall, et al., 2009; Van Belle, Ramon, Lefèvre, & Rossion, 2010; Guo, Smith, Powell, & Nicholls, 2012).

The left gaze bias is not based on particular asymmetries of faces, but rather on the righthemisphere lateralization of the face-processing network. Early patient studies showing face impairments following injury to the right occipital temporal lobe (Benton, 1980; Damasio & Damasio, 1989) have been corroborated by electrophysiological and neuroimaging experiments of healthy, right-handed observers, which show stronger responses to faces in the right hemisphere face-selective regions (Kanwisher, McDermott, & Chun, 1997; Rossion, Joyce, Cottrell, & Tarr, 2003; Yovel, Tambini, & Brandman, 2008; Davidenko, Remus, & Grill-Spector, 2012). In fact, Yovel et al. (2008) found that the right-asymmetry of the fusiform face area predicted individuals' left visual field advantage in face processing.

The vast majority of research examining the left gaze bias in face processing has been conducted using upright face stimuli; however, the in-plane orientation of a face is known to dramatically affect face perception and recognition. Early work by Yin (1969) and Thompson (1980) showed disproportionate impairments in face perception and recognition when faces are rotated by 180° or vertically inverted. In upside-down faces, the typical configuration of face features (two eyes on top, a nose in the middle, and a mouth on the bottom) is disrupted, and so are the holistic face processing mechanisms that rely on that spatial configuration (Marinkovic, Courtney, Witzel, et al., 2014; Zhang, Li, Song, & Liu, 2012). But the disruption of holistic face processing is not limited to inverted faces; impairments are evident in processing sideways faces (Stürzel & Spillmann, 2000; Rossion, 2008),  $\pm 45^\circ$ -tilted faces (Valentine and Bruce, 1988), and even  $\pm 15^\circ$ -tilted faces (Rosenthal, Levakov, & Avidan, 2017).

Although the in-plane orientation of a face has a profound effect on face perception, its effect on fixation behavior is largely unknown. Two past studies have reported differences in how we fixate upright compared to inverted faces (Xu & Tanaka, 2013; Barton, Radcliffe, Cherkasova, et al., 2006); whereas upright faces draw most fixations to the eyes and nose, inverted faces draw most fixations to the nose and mouth. However, no study to our knowledge has systematically examined gaze behavior to faces at intermediate in-plane orientations, and in particular whether and how the left gaze bias manifests in tilted faces.

Geometrically, tilting a face disrupts its horizontal symmetry and creates vertical asymmetries in the placement of features. In particular, one eye ends up higher in the observer's visual field than the other. Based on previous research showing upper field advantages in visual processing (Najemnik & Geisler, 2005; Paulun, Schütz, Michel, et al., 2015), we hypothesized that tilted faces would elicit an *upper eye bias* that would compete with (and possibly override) the left gaze bias in counterclockwise-tilted faces. Here we present data from two eye tracking experiments designed to test this hypothesis. Some of these data were previously reported at the Vision Science Society meeting (Davidenko, Kopalle, & Bridgeman, VSS-2018).

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## **Methods and Results**

## **Experiment 1: Do tilted faces elicit an upper eye bias?**

The goal of Experiment 1 was to determine whether tilting a face image by  $\pm 45^{\circ}$  (thereby introducing a discrepancy in the height of the two eyes) leads observers to fixate more on the upper eye. If the left gaze bias is robust to changes in face orientation, observers should fixate the left eye more than the right eye across upright and tilted faces alike. Alternatively, if there is a fixation bias favoring the upper eye in tilted faces, observers' left gaze bias should be attenuated (or eliminated) in counterclockwise-tilted faces, where the right eye appears higher in the observer's visual field than the left eye.

**Stimuli.** We selected 42 front-view faces (21 female, 21 male) from the FERET face database (Phillips, Wechsler, Huang, Rauss, 1998; Phillips, Moon, Rizvi, Rauss, 2000) lacking any distinguishing characteristics (such as moles or scars) that might bias observers to look more to one side of the face over the other. Images were cropped with an oval region preserving only the face. For the eye tracking experiment, we planned to presented intact or mirror-reversed versions of each face image to different observers, in order to eliminate stimulus-level factors. However, to confirm that mirror-reversing the faces would not produce unusual asymmetries (for example, by reversing "typical" hair styles), we conducted a pilot study to test whether observers could distinguish between intact and mirror-reversed faces. For the pilot study, 23 undergraduates (18 female) from the University of California, Santa Cruz were asked to report whether they thought each of the 42 face images was original or mirror-reversed by pressing one of two buttons. Performance was at chance: the mean proportion correct across the 23 participants was 0.51 (95% CI: [0.48, 0.54]) which did not differ from chance. These pilot data indicate that observers cannot determine whether or not a face image has been mirror-reversed.

**Participants.** For the eye tracking experiment, we recruited 15 participants (10 female) from UC Santa Cruz who were compensated with course credit. Based on previous studies of the left gaze bias, we believed this would be an appropriate sample size to measure the left gaze bias at the three angles of interest. The study was approved by UC Santa Cruz's IRB and

participants gave informed consent before participating. Participants were all right-handed, had normal or corrected-to-normal vision with contact lenses, and were naïve to the purpose of the experiment.

**Procedure.** Participants sat upright, using a chin- and forehead-rest to stabilized their heads. Before the study began, participants' eyes were calibrated with 9 fixations points on the screen. In each trial, participants were first prompted to fixate a central cross. After 2 s, the fixation cross disappeared and a face was displayed such that the tip of the nose appeared in the location where the fixation cross had been. Participants were instructed to judge the expression of the face as smiling or neutral, and wait for an audible beep (which occurred 1.5 s after the face appeared) before responding. Across trials, faces appeared randomly in one of three possible orientations: 0° (upright), +45° (clockwise), or -45° (counterclockwise), with 14 faces shown at each orientation. Across participants, we counterbalanced which faces were shown in the original or mirror-reversed format to eliminate potential stimulus asymmetry effects. The study took approximately 8 minutes to complete.

**Eye tracking.** We used a GazePoint Eye Tracker with 60Hz sampling frequency and 0.5°-1.0° accuracy. Faces subtended approximately 11° (width) by 14° (height) of visual angle when presented upright. Screen recordings superimposed with the interpolated fixation positions were analyzed during the 1.5 s (90 frames) face-exploration phase of face exploration in each trial. First and second fixations in each trial were coded by 3 independent research assistants as fixations lasting 150 ms or more, falling on one of the following locations: left eye (including eyebrow), right eye (including eyebrow), nose (including bridge of the nose), mouth, forehead, or other. To ensure reliability of results, the analyses below are based on trials in which there was agreement between at least two of the three coders, which resulted in an average of 82% usable trials per participant.

# **Results of Experiment 1**

The distribution of first and second fixations to upright and tilted faces is shown in Figure 1. Analysis of first fixations revealed a significant left gaze bias in upright faces, manifesting as a higher proportion of first fixations the left eye (M: 0.19, SE: 0.04) compared to the right

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eye (M: 0.02, SE: 0.02; t(14)=2.16, p=0.05). The left gaze bias was even more apparent in second fixations, with many more second fixations landing on the left eye (M: 0.32, SE: 0.07) compared to the right eye (M: 0.08, SE: 0.04; t(14)=2.87, p=0.01). Critically, the orientation of the face had a strong effect on the distribution of first and second fixations. Clockwise-rotated (+45°) faces elicited a numerically larger left-gaze bias than upright faces, with a higher proportion of first fixations to the left eye (M: 0.34, SE: 0.09) compared to the right eye (M: 0.01, SE: 0.01; t(14)=3.68, p=0.002). In contrast, counterclockwise-rotated (-45°) faces showed the opposite: a strong *right eye bias*, with significantly more fixations to the right eye (M: 0.27, SE: 0.09) compared to the left eye (M: 0.02, SE: 0.01; t(14)=2.92, p=0.01). In other words, the *upper eye* elicited a plurality of first fixations in  $\pm$ 45° tilted faces, regardless of whether it was the left or right eye.



Figure 1. Results of Experiment 1. The average distribution of first (top panel) and second (bottom panel) fixations across 15 participants to the left eye (blue), right eye (red), and other features in upright and titled faces. Error bars denote the standard error of the mean.

This upper eye bias remained just as strong in second fixations, with second fixations to the upper eye (UE) surpassing second fixations to the lower eye (LE) in clockwise-rotated faces ( $M_{UE}$ : 0.31, SE: 0.07 vs.  $M_{LE}$ : 0.04, SE: 0.02; t(14)=3.56, p=0.003) as well as in counterclockwise-rotated faces ( $M_{UE}$ : 0.28, SE: 0.08 vs.  $M_{LE}$ : 0.08, SE: 0.03; t(14)=2.20,

p=0.05; see Figure 1, lower panel). Overall, these results clearly indicate the existence of a robust *upper eye bias* in  $\pm 45^{\circ}$  tilted faces that not only competes with, but dominates the left gaze bias.

#### Experiment 2: At what orientation does the upper eye bias emerge?

It is clear from the results of Experiment 1 that a  $\pm 45^{\circ}$  rotation is sufficient to override participants' left gaze bias in favor of an upper eye bias. The goal of Experiment 2 was to determine more precisely at what angle the upper eye bias emerges, and how fixation patterns change across a broader range of face orientations.

**Stimuli.** For this experiment, we selected 196 faces from the Chicago Face Database (Ma, Correll, & Wittenbrink, 2015); half smiling and half neutral, half female and half male, and half White and half Back. Faces were shown in gray-scale, cropped below the neck, and subtended approximately 10° by 13° of visual angle when upright. Each face was shown at one of 14 orientations (0°,  $\pm 11.25^{\circ}$ ,  $\pm 22.5^{\circ}$ ,  $\pm 37.75^{\circ}$ ,  $\pm 45^{\circ}$ ,  $\pm 90^{\circ}$ ,  $\pm 135^{\circ}$ , and 180°), with 14 unique faces shown at each orientation. As in Experiment 1, we used half intact and half mirror-reversed images to avoid potential stimulus asymmetry effects. The orientation at which each face image was shown, and its presentation as intact or mirror-reversed, was randomized across participants.

**Participants.** We recruited a new group of 13 participants (9 female) from UC Santa Cruz who were compensated with course credit. The study was approved by UC Santa Cruz's IRB and participants were gave informed consent before participating. All participants were naïve to the hypothesis of the experiment, and none had participated in Experiment 1. Participants were all right-handed and had normal or corrected-to-normal vision with contact lenses.

**Procedure.** The procedure was identical to that in Experiment 1, except that there were 196 trials, and the study took approximately 15 minutes to complete.

**Eye tracking.** We used the same GazePoint eye tracker as in Experiment 1 and the same coding paradigm for classifying first and second fixations, with three independent research

assistants coding each participant's data. The analyses below are based on trials in which there was agreement between at least two of the three coders, which resulted in an average of 88% usable trials per participant.

#### **Results of Experiment 2**

The distribution of first and second fixations to faces at different orientations is shown in Figure 2 (top and bottom panels, respectively). Although there was a slight tendency for participants to fixate the left eye (0.11 first fixations, 0.13 second fixations) over the right eye (0.06 first fixations, 0.10 second fixations) in upright faces, this difference did not reach statistical significance (|Ts| < 0.8, Ps>0.4). Of the 13 participants, 6 showed a consistent left gaze bias, 2 showed a consistent right gaze bias, and 5 showed no significant lateral bias to upright faces.



Figure 2. Results of Experiment 2. The average distribution of first (top) and second (bottom) fixations across 13 participants to the left eye (blue), right eye (red), and other features in upright and titled faces. Error bars denote the standard error of the mean. Data at -180° and 180° are the same and shown for symmetry.

Despite a weak left gaze bias to upright faces, tilted faces again elicited a robust *upper eye bias*, not only at -45° and +45° (replicating Experiment 1), but across a wide range of face orientations (see Figure 2, red and blue curves). We found a significantly larger proportion of first fixations to the upper eye compared to the lower eye for faces at  $\pm 90^{\circ}$  (t(9)=2.3, p=0.05),  $\pm 45^{\circ}$  (t(9)=4.7, p=0.001),  $\pm 33.75^{\circ}$  (t(9)=5.1, p=0.0007),  $\pm 22.5^{\circ}$  (t(9)=4.36, p=0.002), and even  $\pm 11.25^{\circ}$  (t(9)=2.38, p=0.04). That is, with as little as a  $\pm 11.25^{\circ}$  tilt of the face, participants showed a consistent tendency to make first fixations toward the upper eye. The results were nearly identical for second fixations (see Figure 2, bottom panel).

Our data revealed several other interesting gaze patterns for face orientations beyond  $\pm 45^{\circ}$ . First, sideways faces (at +90° or -90°) elicited significantly fewer first fixations to the upper eye (0.12 and 0.10, respectively) compared to 45° or -45° faces (0.40 and 0.39, respectively; |Ts|>3.6, Ps<0.004), suggesting that the upper eye bias may peak closer to  $\pm 45^{\circ}$  rather than  $\pm 90^{\circ}$ , where the two eyes have maximum vertical distance. Second, upside-down faces (180°) elicited a majority of fixations to the mouth region, corroborating past findings (Xu & Tanaka, 2013; Barton et al., 2006). Considering the pattern of fixations across all face orientations suggests there may be a general "upper feature bias" when looking at rotated faces: the upper-most feature (whether it is the left eye, right eye, or the mouth) draws observers' gaze.

We also found that *overall fixations to the eyes* (defined as the proportion of combined fixations to the left and right eyes) were more frequent in tilted compared to upright faces (which in turn drew most fixations to the nose; see Figure 2, yellow curve). For example, the average proportion of fixations to the eyes in  $\pm 45^{\circ}$  faces was 0.42 compared to 0.17 for upright faces, a significant difference (t(12)=3.20, p=0.008). The proportion of fixations to the eyes was also higher in faces at  $\pm 37.75^{\circ}$  (M=0.38, t(12)=3.35, p=0.006) and  $\pm 22.5^{\circ}$  (M=0.30, t(12)=2.31, p=0.04) compared to upright faces (M=0.17). Thus, our data show not only that tilted faces elicit a plurality of fixations to the upper eye, but they draw more overall fixations to the eyes than upright faces.

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#### Performance in the expression judgment tasks

In Experiment 1, we used face images that were classified as having a neutral expression in the FERET database; nevertheless, participants did not consider most of these faces as neutral, and responded that they were smiling on 65% of trials. Because we did not include truly smiling faces, we could not distinguish between performance and a "smiling bias" in this task. In Experiment 2, half of the faces were truly smiling and half were neutral. However, behavioral performance on the expression judgment task was near ceiling (94.4% on average) and did not vary significantly across orientations (F(13,181)=1.3, p=0.2). This is not surprising, since the expressions were obvious and participants had at least 1.5 s to scan each face before responding. Thus, our tasks in Experiments 1 and 2 were not ideally designed to examine potential relationships between fixation behavior and performance in judging expressions across orientations.

# Robustness of the upper eye bias across experiments

Although different faces were used in the two experiments, we conducted a cross-experiment analysis defining an 'upper eye bias index' for each participant, as the proportion of upper eye minus lower eye fixations, averaged across  $-45^{\circ}$  and  $+45^{\circ}$  faces, and collapsed across first and second fixations. The index ranges from -1 to +1, negative values indicating a lower eye bias, and positive values indicating an upper eye bias. Of the 28 total participants, 26 showed an upper eye bias, 1 showed a lower eye bias, and 1 showed no bias (see Figure 3).



Figure 3. Distribution of the 'upper eye bias index' in ±45° faces across the 28 participants in Experiments 1 and 2. Positive values indicate more fixations to the upper than lower eye.

# **General Discussion**

We have shown for the first time that *tilted faces* elicit a strong *upper eye bias* – a tendency to fixate the upper eye over the lower eye. This bias is evident in first and second fixations, and it is strong enough to override the left gaze bias for faces at a range of tilts. Moreover, tilted faces resulted in more overall fixations to the eyes compared to upright faces. Here we consider potential mechanisms of the upper eye bias and discuss implications for research in social perception and cognition.

# Mechanisms: general or face-specific?

What are the mechanisms of the upper eye bias in tilted faces? One possibility is that the upper eye bias arises from a general (not face-specific) tendency to attend to stimuli in the upper visual field (Najemnik & Geisler, 2005; Paulun et al., 2015). Our face stimuli were always presented such that the initial fixation was on the tip of the nose. Therefore, we cannot distinguish whether the upper eye bias reflects a tendency for observers to fixate the eye that is higher up on the face, or simply to fixate the eye that is more directly above the initial fixation point. Future experiments may dissociate these possibilities by presenting tilted faces in different positions across the visual field (see Luke & Pollux, 2016).

The upper eye bias in tilted faces may also reflect a face-specific fixation strategy. Previous research indicates there is an "optimal" viewing position when processing upright faces, typically just below the eyes and slightly left of center (although the exact position varies across tasks and individuals; Hsiao & Liu, 2012; Peterson & Eckstein, 2012; 2013; Peterson, Lin, Zaun, & Kanwisher, 2016; Arizpe, Walsh, Yovel, & Baker, 2016; de Haas, Schwarzkopf, Alvarez, et al., 2016). From this optimal fixation position, the eyes end up slightly above and lateral to fixation, and nose and the mouth end up below fixation. Recent neuroimaging evidence suggests that responses in face-selective cortex may be tuned to these typical feature positions (de Haas et al., 2016). Thus, the tendency to fixate just below the eyes in upright faces may serve to optimize the positions of the remaining face features within the observer's visual field for face processing.

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However, when an observer is presented with a *tilted* face, the upper eye might represent a new optimal fixation position. In particular, fixating the upper eye places the remaining face features in more "typical" positions in the visual field, than fixating the lower eye. For example, if an observer fixates the upper (right) eye of a  $-45^{\circ}$  (counterclockwise) face, the nose and mouth fall directly below fixation, which is optimal (see Figure 1). In contrast, if the observer fixates the *lower* (left) eye of a  $-45^{\circ}$  face, the nose and mouth fall to the left of fixation, which is not optimal. Thus, the upper eye bias in tilted faces may serve as a strategy to place the remaining face features closer to their optimal positions in the observer's visual field.

#### **Open questions**

Our results leave open the important question of how the upper eye bias depends on the task and social context in which tilted faces appear. Here we employed an expression judgment task with static face images, but we posit that the upper eye bias is likely to emerge across contexts. Because our expression judgment tasks either had no truly smiling faces (Experiment 1) or elicited ceiling performance (Experiment 2), we could not determine whether fixating the upper eye aids or hinders performance in expression judgments. Future studies can employ different (and in particular, more difficult) face perception tasks to examine how performance and gaze patterns depend on the tilt of the face.

Another open question is how the upper eye bias may manifest outside of the lab, where individual differences and social factors play a large role in gaze behavior. Although a left gaze bias has been reported during audio-visual speech perception with dynamic faces (Everdale, Marsch, & Yurick, 2007), it is unknown how these findings extend to tilted faces. In real-life, face-to-face conversations, our heads do not always remain upright; conversational partners often tilt their heads in their nonverbal communication, sometimes in parallel and sometimes in opposite directions of one another (Ishi, Ishiguro, & Hagita, 2014). It is likely then, that the angular disparity between partners' faces will often be large enough to influence their mutual gaze behavior. Our results would predict that the more the two partners' faces deviate in their relative orientations, the more each partner will fixate the other's upper eye.

Finally, our finding that tilted faces led to more *overall fixations to the eyes* than upright faces may have intriguing implications for research in social perception and cognition. For example, individuals diagnosed with Autism Spectrum Disorder (ASD) often show impairments in face processing and exhibit atypical gaze patterns to faces, tending to avoid looking at the eyes, and looking more at the mouth (Dalton, Nacewicz, Johnstone, et al., 2005; Behrmann, Thomas, & Humphreys, 2006). This atypical gaze behavior is not just diagnostic of social cognitive impairments, but it can perpetuate these impairments by providing the visual system with sub-optimal information for face processing (Tanaka & Sung, 2016). Although our studies were run on a neuro-typical population of undergraduate students, it would be intriguing to examine whether tilted faces also elicit more eye-directed fixations in ASD individuals, and whether such a change in gaze behavior could lead to improvements in face perception.

# Conclusion

We have shown for the first time that tilted faces elicit an *upper eye bias* – a strong tendency to fixate the upper eye over the lower eye. This upper eye bias can be detected with as little as an  $\pm 11.25^{\circ}$  tilt and appears to peak with a  $\pm 45^{\circ}$  tilt of the face. The upper eye bias in tilted faces dominates the more well-documented left-gaze bias at a range of orientations, and leads to tilted faces receiving more overall fixations to the eyes than upright faces. As such, the upper eye bias has potential implications for research in social perception and cognition.

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Figure 1. Results of Experiment 1. The average distribution of first (top panel) and second (bottom panel) fixations across 15 participants to the left eye (blue), right eye (red), and other features in upright and titled faces. Error bars denote the standard error of the mean.

190x190mm (160 x 160 DPI)



Figure 2. Results of Experiment 2. The average distribution of first (top) and second (bottom) fixations across 13 participants to the left eye (blue), right eye (red), and other features in upright and titled faces. Error bars denote the standard error of the mean. Data at -180° and +180° are the same and shown for symmetry.

423x288mm (72 x 72 DPI)

