Gaze inversion effect: Sex invariance and difference in gaze direction sensitivity

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Abstract

Even though humans are adept at distinguishing various faces, inversion dramatically spoils the ability. This face inversion effect is remarkably robust across observers; however, whether inversion impairs the perception of facial parts (particularly the eye) is inconsistent across studies. Some studies have shown that featural processing remains preserved or even enhanced when faces are inverted, while others have shown that inversion impairs featural processing. These mixed findings may result from confounding factors such as a small number of participants, an imbalanced participant sex ratio, and the varying nature of the tasks in previous reports. To address these issues, we assessed the effect sizes of face orientation, sex, and their interaction in low-level psychophysical discrimination of briefly presented gaze stimuli in a well-powered cohort with a balanced sex ratio (N = 190). The results revealed a medium-to-large-sized effect of inversion (f = 0.35) and a small-to-medium-sized effect of sex (f = 0.17) on gaze direction discrimination but no meaningful interaction (f = 0.05). Thus, our results demonstrated an almost equivalent gaze inversion effect between females and males (sex invariance) and a female superiority in overall gaze direction sensitivity (sex difference). We suggest that inversion impairs sensitivity to gaze direction, but whether it leads to a change in explicit behavioral performance may depend on specific task settings rather than the participant's sex.

Keywords:

Gaze inversion effect; Face inversion effect; Gaze perception; Sex invariance; Sex difference

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Abbreviation:

FIE: face inversion effect; GIE: gaze inversion effect

Competing interests:

None of the authors have any potential conflicts of interest.

Authors' contributions:

All authors designed the study and wrote the manuscript. DM and KK collected stimulus materials. DM collected and analyzed the data.

1. Introduction

Humans are experts at distinguishing and recognizing faces under various conditions. People can (albeit explicitly or implicitly) detect subtle differences and distinguish between thousands of individuals even though typical human faces share strikingly similar morphology (e.g., two eyes at the top, a nose in the middle, and a mouth at the bottom of a frontal face). However, the case is remarkably different for inverted faces (Yin, 1969). Turning a face upside-down makes it particularly difficult to recognize, whereas inverting other types of objects do not affect recognition performance as much.

This face inversion effect (FIE) is exceptionally robust across observers and conditions. It has led researchers to speculate that there are *qualitative* differences between upright and inverted face processing; upright face processing involves holistic or configural processing of faces, whereas inverted face processing involves piece-meal or parts-based processing of faces (Maurer et al., 2002). This holistic or configural processing assumes that perceiving a face as a coherent whole (rather than as a collection of separate elements) is an idiosyncratic feature that makes face recognition special (Farah et al., 1998; Moscovitch et al., 1997). By contrast, recent studies have suggested that the differences in processing upright and inverted faces are *quantitative* (i.e., a matter of degree) rather than qualitative (i.e., distinct processing style) (Gold et al., 2012; Jiang et al., 2006; Matsuyoshi et al., 2015; Sekuler et al., 2004). Sekuler et al. (2004) used a response classification technique to reveal the most discriminative stimulus regions that affected performance. They found that people used similar local regions of faces for discrimination

in both upright and inverted face conditions. In addition, Gold et al. (2012) showed that the perception of a face is no better than would be predicted by the facial feature integration of an optimal Bayesian integrator. If observers use a holistic face representation, they should show superoptimal performance for a whole face (better than the sum of its parts); however, the performance was comparable to the integrated prediction derived from individual facial features presented in isolation. Contrary to the qualitative view, these results support the quantitative view where humans use a similar recognition strategy between upright and inverted faces. However, the two views are not mutually exclusive; dissociable neural pathways may mediate the two mechanisms (Matsuyoshi et al., 2015).

The behavioral FIE itself is very strong, as rigorous replications have confirmed it; however, it is unclear whether inversion impairs the perception of individual facial features. In particular, whether the sensitivity to eye or gaze processing differs as a function of face orientation remains to be clarified. Several studies have shown that inversion has little effect on distinguishing faces that differ only in the shape of individual features (Freire et al., 2000; Le Grand et al., 2001). For example, although upright faces with different hairstyles and costumes tend to be perceived as different individuals even though their internal features are identical (Sinha & Poggio, 1996), composite face procedures (Murphy et al., 2017) have shown that inversion remarkably improves the ability to identify them (Hole, 1994; Young et al., 1987). Furthermore, Xu and Tanaka (2013) showed that inversion had little or no effect on discriminating featural and configural differences in the eye region (while severely disrupting the perception of changes in the lower region of the face). These results suggest that featural processing, at least eye or gaze processing, is preserved or sometimes enhanced when faces are

upside-down. By contrast, numerous studies have shown the opposite: featural processing becomes difficult when faces are inverted. One notable example is the Thatcher illusion (Thompson, 1980). People fail to notice local feature changes in an inverted face, even though the changes are evident in an upright face. Furthermore, studies have suggested that an isolated feature (without a face context) alone can produce inversion effects (Leder et al., 2001; Rakover & Teucher, 1997). These findings indicate that it is difficult to process individual features when they are upside-down.

Because of the variation among studies (e.g., sample size, sex ratio, study design, and task settings), these discrepancies are difficult to resolve. In particular, sample size and sex ratio would be the most important factors in face processing studies. Insufficient statistical power due to a small sample size likely leads to false positives and undermines the reliability of findings (Button et al., 2013; Simmons et al., 2011). Furthermore, although females often outperform males in face processing performance (Bayliss et al., 2005; Goodman et al., 2012; Heisz et al., 2013; Matsuyoshi et al., 2014; Matsuyoshi & Watanabe, 2021; McClure, 2000), studies have not always paid attention to the participant sex ratio unless the study focuses on sex differences. Since participant sex can interact with primary behavioral measures of interest (Cellerino et al., 2004; Lewin & Herlitz, 2002; Matsuyoshi et al., 2014), an imbalanced sex ratio likely impinges on the conclusion of whether inversion affects featural processing.

To address these issues, we examined the effects of inversion and sex on featural processing in a well-powered cohort with a balanced sex ratio. We determined our sample size based on an a priori power analysis, which allowed us to assess whether inversion affects featural processing and whether sex interacts with it. In addition, we investigated

low-level psychophysical discrimination of gaze direction as it is crucial to determine the effects of inversion on facial feature processing. The current approach allowed us to estimate a more accurate effect size of inversion on featural processing while controlling for possible confounding sources emanating from higher cognitive processes, a small sample size, or an imbalanced sex ratio.

2. Materials and Methods

2.1 Participants

We assumed a medium-sized effect of sex on gaze direction discrimination based on studies showing sex differences in face or gaze perception (Bayliss et al., 2005; Goodman et al., 2012; Matsuyoshi et al., 2014; Matsuyoshi & Watanabe, 2021). To achieve a power ($1 - \beta$) of 0.95 and a medium effect size (Cohen's $f = 0.25$) while assuming a high correlation between the measures ($r = 0.7$ between upright and inverted gaze processing), a sample of 180 (90 for each group) is required to detect a significant difference ($\alpha = 0.05$) between participant sexes (Cohen, 1988; Faul et al., 2007). In addition, we conservatively assumed the effect size of inversion as small-to-medium (Cohen's $f = 0.15$) because of the mixed results of previous studies. A sample of 90 (45 for each group) is required to detect a significant difference ($\alpha = 0.05$, $1 - \beta = 0.95$, $r = 0.7$) between upright and inverted faces with a small-to-medium effect size, and a sample of 90 (45 for each group) is required to detect a significant interaction ($\alpha = 0.05$, $1 - \beta = 0.95$, $r = 0.7$) between the face orientation and sex with a small-to-medium effect size. Therefore, we decided to recruit a sample of more than 200 participants to confirm small-to-medium-sized effects between conditions and to overcome the potential loss of analyzable data, often caused by participants' inappropriate responses or technical errors.

Two hundred and thirteen young adults participated. All had normal or corrected-to-normal vision, and none reported a history of neurological or developmental disorders. The procedures were made following the Declaration of Helsinki and approved by the Committee of Ethics, Waseda University, Japan. Each participant gave written

informed consent before the experiment. Twenty-three participants were excluded from further analysis because they did not perform the task correctly (their performance did not reach the 60% level at an angle of 0°). After these exclusions, data from 190 participants (self-reported 92 females, 98 males; mean age: 21.3 years; range: 18-29 years) remained for analysis.

2.2 Stimuli

Face images were taken from three male and three female models, looking either directly at a camera (0°) or 10°, 20°, or 30° to the left or right with their face square to the camera, photographed by the authors (Matsuyoshi et al., 2014). Images were gray-scaled and subtended approximately 12 by 17° of the visual angle. The mean brightness was normalized across images. A mask stimulus was generated by grid-scrambling an averaged image of the face stimuli.

2.3 Procedure

Participants viewed the stimuli on a 21-inch CRT monitor at a distance of 57 cm with their heads resting on a chin-rest and judged whether the eyes were looking directly at them (Matsuyoshi et al., 2014). All stimuli were presented against a black background. Each trial began with an upright or inverted face stimulus (20 ms) followed by a brief blank screen (20, 40, or 60 ms), a visual mask (100 ms), and finally, a cross (until response) (Fig. 1). Face images were either direct gaze (0°), or left- or right-averted gaze (10°, 20°, or 30°). The vertical positions of the eyes were aligned between upright and inverted faces and located along the vertical center of the display. We used a variable

inter-stimulus interval (ISI) between the face and the mask to control task difficulty. Each left or right angle was presented 12 times, except for 0° stimuli, which were presented 24 times, for each of the three ISIs for both face orientations, resulting in 576 trials in total (6 gaze angles [left or right 10-30°] × 3 ISIs × 2 face orientations × 12 trials + 1 gaze angle [0°] × 3 ISIs × 2 face orientations × 24 trials). The two face orientations were presented separately in four alternating blocks of 144 trials each, with the order counterbalanced across participants (i.e., either upright-inverted-upright-inverted or inverted-upright-inverted-upright). Gaze directions and ISIs were randomized across trials. Participants performed the main experiment after 30 practice trials.

2.4 Analysis

Responses from left- and right-averted gaze stimuli were pooled for each absolute angle. In addition, responses from different ISIs were also pooled. The gaze threshold was defined as the angle at which a 50% response was obtained, as estimated by a local linear fit of a nonparametric psychometric function (Żychaluk & Foster, 2009) to each observer's ‘direct’ responses as a function of gaze angle. A higher threshold was considered to be less sensitive to gaze direction. We set the statistical thresholds to $\alpha = 0.05$.

3. Results

3.1 Psychometric functions

We performed a repeated-measures ANOVA (degrees of freedom were Greenhouse-Geisser corrected in case of sphericity violation) on participants' 'direct' responses with angle (0°, 10°, 20°, 30°) and face orientation (upright, inverted) as within-subject factors and participant sex (male, female) as a between-subject factor (Fig. 2a). The main effects of the angle ($F_{(1.989,373.885)} = 4796.9115$, $p = 9.8544 \times 10^{-270}$, $\eta_p^2 = 0.9636$, $\omega_G^2 = 0.8809$, Cohen's $f = 2.7367$), face orientation ($F_{(1,188)} = 158.2230$, $p = 1.0070 \times 10^{-26}$, $\eta_p^2 = 0.4570$, $\omega_G^2 = 0.0639$, Cohen's $f = 0.0909$), and participant sex ($F_{(1,188)} = 9.7583$, $p = 2.0068 \times 10^{-26}$, $\eta_p^2 = 0.0493$, $\omega_G^2 = 0.0141$, Cohen's $f = 0.0436$) were significant. This demonstrated a decrease in 'direct' responses with increasing angle, higher 'direct' responses in the inverted compared to the upright face condition, and higher 'direct' responses in male compared to female participants, respectively.

We found significant interactions between the angle and orientation ($F_{2.143,402.849} = 276.8289$, $p = 9.4991 \times 10^{-80}$, $\eta_p^2 = 0.5960$, $\omega_G^2 = 0.1171$, Cohen's $f = 0.1270$) and between the angle and participant sex ($F_{1.989,373.885} = 6.8471$, $p = 0.0012$, $\eta_p^2 = 0.0351$, $\omega_G^2 = 0.0086$, Cohen's $f = 0.0350$), while no significant interactions were found between the orientation and sex ($F_{1,188} = 1.6217$, $p = 0.2044$, $\eta_p^2 = 0.0086$, $\omega_G^2 = 0.0003$, Cohen's $f = 0.0092$) and between the angle, orientation, and sex ($F_{2.143,402.849} = 0.9617$, $p = 0.3881$, $\eta_p^2 = 0.0051$, $\omega_G^2 = -1.8401 \times 10^{-5}$, Cohen's $f = 0.0074$). Follow-up tests revealed higher 'direct' responses in the upright compared with the inverted face

condition at an angle of 0° ($F_{1,188}$ = 68.2900, p = 2.4857 × 10^{-14}, η_p^2 = 0.2665, ω_G^2 = 0.0935, Cohen's f = 0.3251), and higher 'direct' responses in the inverted compared to the upright face condition at angles between 10 and 30° ($F_{1,188}$ values > 65.8134, p values < 6.2740 × 10^{-14}, η_p^2 values > 0.2592, ω_G^2 values > 0.0835, Cohen's f values > 0.2978). In addition, males showed higher 'direct' responses at angles between 10 and 30° than females ($F_{1,188}$ values > 8.6726, p values < 0.0036, η_p^2 values > 0.0441, ω_G^2 values > 0.0311, Cohen's f values > 0.1651). By contrast, males and females showed similar 'direct' responses at an angle of 0° ($F_{1,188}$ = 0.2151, p = 0.6433, η_p^2 = 0.0011, ω_G^2 = −0.0029, Cohen's f = 0.0271).

3.2 Gaze thresholds

A 2 (upright, inverted) × 2 (male, female) repeated-measures ANOVA on the 50% gaze perception threshold (Fig. 2b) showed a significant main effect of face orientation ($F_{1,188}$ = 109.6661, p = 1.6503 × 10^{-20}, η_p^2 = 0.3684, ω_G^2 = 0.1112, Cohen's f = 0.3515) with a larger threshold in the inverted compared to the upright face condition (medium-to-large effect size), and a significant main effect of sex ($F_{1,188}$ = 7.4251, p = 0.0070, η_p^2 = 0.0380, ω_G^2 = 0.0257, Cohen's f = 0.1652) with a larger threshold for male compared to female participants (small-to-medium effect size). However, there was no significant interaction between the face orientation and participant sex ($F_{1,188}$ = 2.0730, p = 0.1516, η_p^2 = 0.0109, ω_G^2 = 0.0012, Cohen's f = 0.0456), showing that females and males suffered similarly from inversion (females, t_{91} = 6.6386, p = 2.2441 × 10^{-9}, Cohen's d = 0.6921 [95% CI: 0.3936, 0.9888]; males, t_{97} = 8.1743, p = 1.1419 × 10^{-12}, Cohen's d = 0.8257 [95% CI: 0.5330, 1.1165]; females − males, $t_{187.748}$ = 1.4443, p =

0.1503, Cohen's d = 0.2097 [95% CI: −0.0759, 0.4947]), whereas females had a higher sensitivity than males for discriminating gaze direction irrespective of face orientation (upright, $t_{170.178}$ = 2.3087, p = 0.0221, Cohen's d = 0.3351 [95% CI: 0.0481, 0.6212]; inverted, $t_{177.046}$ = 2.6104, p = 0.0098, Cohen's d = 0.3789 [95% CI: 0.0913, 0.6655]).

There was a significant strong correlation between the upright and inverted gaze thresholds (Fig. 2c; overall, r = 0.6315, $p = 1.5559 \times 10^{-22}$; males, r = 0.6933, $p = 2.5310 \times 10^{-15}$; females, r = 0.4606, $p = 3.8444 \times 10^{-6}$), indicating an overlap between upright and inverted gaze processing. The correlation was significantly greater in males than in females (z = 2.4154, p = 0.0157). Note, however, that the difference was not so strong that excluding one male and one female outlier (who showed the largest inverted gaze thresholds) resulted in a conventional marginal significance level (z = 1.8829, p = 0.0597).

4. Discussion

Our results demonstrated that inversion impaired (but did not preserve or enhance) gaze direction sensitivity using a well-powered cohort with an a priori determined sample size. The absence of a significant interaction between sex and face orientation indicates that the gaze inversion effect (GIE) was not dependent on sex (i.e., sex invariant), although the overall sensitivity was higher in females than in males (sex difference). These results suggest that inversion does impair gaze direction sensitivity. Our results support the quantitative view of the inversion effects, which assumes impaired featural processing (Gold et al., 2012; Sekuler et al., 2004), and are inconsistent with the stringent qualitative view, which postulates preserved or enhanced featural processing (Le Grand et al., 2001; Leder & Bruce, 1998; Rossion, 2008; Tanaka & Sengco, 1997; Xu & Tanaka, 2013). Given that the quantitative and qualitative mechanisms underlying the inversion effects can be dissociable in neural pathways (Matsuyoshi et al., 2015), our results do not necessarily provide strong support for either view. Instead, our findings suggest a nuanced perspective, providing a refutation of the strict quantitative view rather than the ultimate proof of the quantitative view. One might argue that the GIE provides evidence of qualitative differences in upright and inverted face processing, as it likely reflects holistic processing within the eye for an upright face. However, our findings are (at least) inconsistent with the strict qualitative view, which assumes preserved parts-based processing for inverted faces.

4.1 Qualitative and quantitative views of the inversion effects

Several studies have suggested that inversion preserves featural processing while severely impairing holistic or configural processing, such as the distance between features (Freire et al., 2000; Le Grand et al., 2001; Rossion, 2008; Tanaka & Sengco, 1997; Young et al., 1987). The qualitative view predicts the comparable performance between upright and inverted face processing because inversion prompts feature-based encoding of faces (Farah et al., 1995). In particular, it has been suggested that the eye is the least likely facial feature to be affected by inversion compared to other parts of the face: Xu and Tanaka (2013) showed that inversion did not affect the perception of changes in the eye region, whereas it degraded the perception of changes in the mouth region (N = 22, 40% female). Although their results seem inconsistent with our results, their task presented a face stimulus for 500 ms, which was significantly longer than our experiment. The longer encoding duration likely alleviated or masked the lower sensitivity to inverted gaze relative to upright gaze. Indeed, behavioral performance was close to 90% in their study, perhaps reflecting a ceiling effect.

By contrast, the quantitative view predicts the opposite, assuming general inefficiency for inverted relative to upright faces (Gold et al., 2012; Jiang et al., 2006; Sekuler et al., 2004). Although using a between-participants design, a small population (N = 6 each), and an unknown sex ratio, Jenkins and Langton (2003) reported that inversion exacerbated gaze direction sensitivity. Furthermore, Rakover and Teucher (1997) (N = 16, 73% female) and Leder et al. (2001) (N = 20, 90% female) found difficulty in processing individual features when they were inverted. However, the small sample sizes and unbalanced or unknown sex ratio made the results inconclusive.

Leveraging a well-powered cohort and a balanced sex ratio, we provide clear evidence for an impairment of featural processing (at least gaze direction sensitivity) by inversion.

4.2 The effects of task settings on inversion effects

Although we demonstrated an impairment of featural processing by inversion, many studies (Freire et al., 2000; Hole, 1994; Le Grand et al., 2001; Young et al., 1987), including large-sample studies (N = 242–282) (Rezlescu et al., 2017; Susilo et al., 2013), have confirmed the preserved (or sometimes better) ability to compare individual features when faces are inverted. The apparent inconsistency would not result from low statistical power or an imbalanced sex ratio as those (and our) studies included large populations, and we (48% female) and Susilo et al. (2013) (52% female) achieved a balanced sex ratio. We suggest that it is rather the task settings that have produced the apparent inconsistency. Featural processing is sometimes preserved (or enhanced) despite the diminished sensitivity, perhaps not because parts-based processing is dominant for inverted faces (Farah et al., 1995; Tanaka & Farah, 1993), but because the tasks require discrimination between exemplars from the same facial parts (e.g., comparing the eyes of different people). Thus, even though perceptual sensitivity per se decreases, the ability to compare two signals is relatively unlikely to deteriorate because sensitivity to both signals, but not one or the other, decreases. Moreover, the apparent dominance of feature-based processing for inverted faces may result from difficulty decomposing facial parts for upright faces, rather than enhanced featural processing for inverted faces. Processing an upright face likely involves tight integration of internal features, making it difficult to parse the face into isolated features (Maurer et al., 2002); however, an inverted face is

unlikely subject to this integration. Therefore, whether inversion leads to a change in explicit behavioral performance may depend on specific task settings rather than the participant's sex.

Note that the effect size of the GIE was smaller than that of the typical FIE. Despite a huge effect of the FIE in a face recognition task (d = 1.298) (Matsuyoshi et al., 2015), we found a medium-to-large effect of the GIE in the present study (d = 0.761, all participants combined). One reason for the tremendous difference in effect size might be that a whole face accumulates the inversion effects of each feature (Gold et al., 2012). Although the susceptibility to inversion may differ across parts (Rakover & Teucher, 1997; Xu & Tanaka, 2013), they may aggregate to produce a large effect size of the FIE. Alternatively, the large effect size difference may simply be explained by the difference in processing load required by each task. The present task encouraged observers to focus on the eyes, whereas typical FIE tasks do not explicitly encourage observers to focus on a local feature but rather on a whole face. Encoding a whole face might be more difficult than encoding a single feature of the face.

4.3 Sex differences in face and gaze processing

Consistent with numerous studies showing female advantages in face processing (Bayliss et al., 2005; Goodman et al., 2012; Heisz et al., 2013; Matsuyoshi et al., 2014; Matsuyoshi & Watanabe, 2021; McClure, 2000), we found that females outperformed males in gaze direction sensitivity. It is worth noting that the effect size observed for the female advantage in upright gaze direction sensitivity (Cohen's d = 0.3351) was far smaller than that for upright face recognition in a previous study (Cohen's d = 0.6426, N

= 180, 45% female) (Matsuyoshi & Watanabe, 2021). This indicates that featural processing is likely to manifest weaker effects (i.e., inversion effects and female advantage) than whole-face processing, as in the effect size difference between the GIE and FIE.

What exactly causes the sex differences in face and gaze processing remains to be investigated, although studies have suggested that not only genetic but also non-genetic factors together contribute to sex differences in behavioral phenotypes (Bölte et al., 2023; Kiesow et al., 2020; Kundakovic & Tickerhoof, 2024). For example, studies on sex differences in nonverbal communication have suggested that sex differences may exist because people possess stereotypes about them (Briton & Hall, 1995). We cannot, of course, rule out the possibility that they are real sex differences tightly regulated by genetic factors such as sex hormones; however, internalized social norms or stereotypes may continue to influence us throughout our lives (Crandall et al., 2002; Gavrilets & Richerson, 2017; Rutland et al., 2005). These social factors may also affect sex differences in face and gaze differences.

A notable limitation of our study is that we treated sex/gender in a binary fashion and findings solely depended on self-reported sex/gender. Outcomes can vary across individuals of different birth-assigned sexes and gender identities (Bölte et al., 2023; Joel, 2021). The definitions of sex/gender are continuously evolving and sex/gender is now considered a spectrum (Ainsworth, 2015; Kundakovic & Tickerhoof, 2024; Rosenthal, 2021). Future research taking human variation in the sex/gender spectrum into account will further elucidate the roles sex/gender play in face and gaze processing.

4.4 Conclusion

In conclusion, our results provide clear evidence for an inversion-induced decrease in the perception of gaze direction (GIE). We found both sex invariance (almost equivalent GIE between females and males) and sex difference (small-to-medium-sized female superiority) in gaze direction sensitivity. Although previous findings regarding the effects of inversion on gaze direction processing are mixed, the a priori determined sample size and the balanced sex ratio in our participants allowed us to characterize the effect sizes for gaze direction sensitivity. Although our findings do not provide definitive evidence to resolve the qualitative vs. quantitative debate over the mechanisms of FIE, we suggest that it is difficult to accept the strict quantitative view of the FIE that assumes preserved featural processing for inverted faces. It may be "apparently preserved," perhaps because some tasks did not require participants to process features in a time-limited manner, and hence, there were redundant cues or processes to overcome the impoverished perceptual sensitivity induced by inversion. Since we did not incorporate tasks other than the discrimination of gaze direction, further research is required to confirm the critical conditions that discriminate between preserved and impoverished featural processing by inversion. Nevertheless, our results demonstrate that inversion does decrease perceptual sensitivity, at least for gaze direction, using a well-powered cohort with a balanced sex ratio.

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Figure Legends

Figure 1. Experimental Paradigm.

Schematic presentation of the experimental task. Upright and inverted faces were presented in different blocks (4 [2 upright + 2 inverted] blocks × 144 trials).

Figure 2. Experimental Results.

(a) Gaze angle psychometric functions. Mean percentage of 'direct' responses (y-axis), plotted as a function of gaze angle (x-axis) × participant sex (female = red, male = blue) × face orientation (upright face = filled circle with a solid line, inverted face = open circle with dashed line). Shaded areas represent 95% confidence intervals of the mean. (b) Mean gaze threshold (angle of 50% reported as direct, which was estimated from the psychometric function) as a function of participant sex (female = red, male = blue) × face orientation (upright face = filled, inverted face = open). Error bars represent 95% confidence intervals of the mean. (c) Scatter plot and density curves of individual upright and inverted gaze thresholds (female = red, male = blue). The gray dashed line indicates identical gaze thresholds between upright and inverted faces (i.e., no gaze inversion effect).

Figures

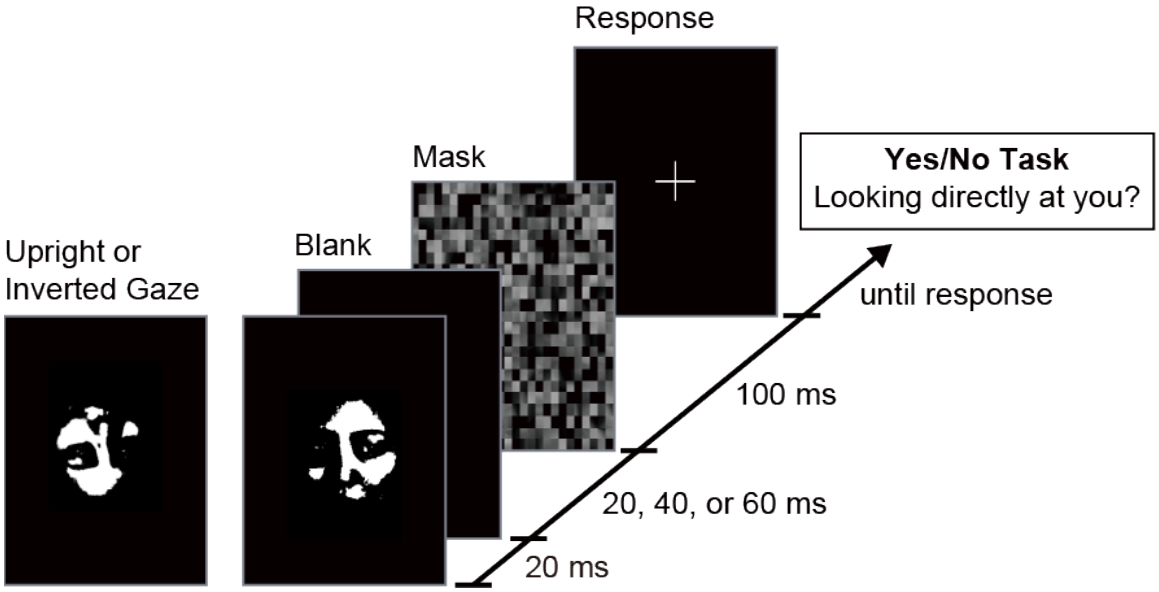

Figure 1

** The face image was deidentified for bioRxiv.*

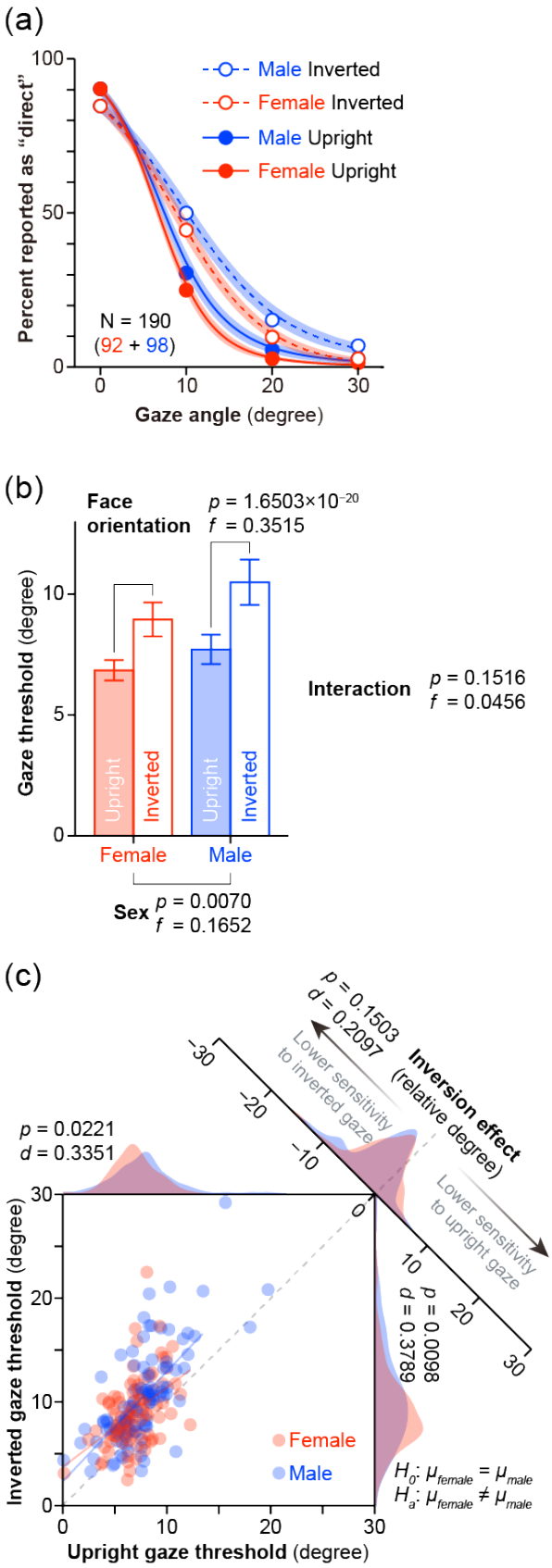
(a)
Male Inverted
Female Inverted
Male Upright
Female Upright
Percent reported as "direct"
N = 190
(92 + 98)
Gaze angle (degree)
(b)
Face orientation
p = 1.6503×10⁻²⁰
f = 0.3515
Gaze threshold (degree)
Upright
Inverted
Upright
Inverted
Female
Male
Interaction
p = 0.1516
f = 0.0456
Sex
p = 0.0070
f = 0.1652
(c)
p = 0.1503
d = 0.2097
Inversion effect
(relative degree)
Lower sensitivity to inverted gaze
Lower sensitivity to upright gaze
p = 0.0221
d = 0.3351
p = 0.0098
d = 0.3789
Inverted gaze threshold (degree)
Female
Male
H0: μfemale = μmale
Ha: μfemale ≠ μmale
Upright gaze threshold (degree)

Figure 2