Unconscious processing of direct gaze: Evidence from an ERP study

Takemasa Yokoyama, Yasuki Noguchi, Shinichi Kita

Abstract

Humans detect faces with direct gaze more rapidly than they do faces with averted gaze. Evidence suggests that the visual information of faces with direct gaze reaches conscious awareness faster than that of faces with averted gaze. This suggests that faces with direct gaze are effectively processed in the brain before they reach conscious awareness; however, it is unclear how the unconscious perception of faces with direct gaze is processed in the brain. To address this unanswered question, we recorded event-related potentials while observers viewed faces with direct or averted gaze that were either visible or rendered invisible during continuous flash suppression. We observed that invisible faces with direct gaze elicited significantly larger negative deflections than did invisible faces with averted gaze at 200, 250, and 350 ms over the parietal electrodes, whereas we did not observe such effects when facial images were visible. Our results suggest that the visual information of faces with direct gaze is preferentially processed in the brain when they are presented unconsciously.

Keywords:
Direct gaze
Interocular suppression
Unconscious processing
Event-related potentials
Conscious awareness

1. Introduction

Eye gaze of a conspecific conveys rich signals to an observer. Thus, gaze plays a critical role in visual processing of a face. Research on gaze perception deals mainly with two types of gaze: averted gaze, which is not directed at the observer, and direct gaze, which is directed at the observer. These two types of gaze have different effects on the perception and cognition of observers.

This functional dissociation between faces with direct and averted gaze is typically seen in their influences on attention of observers. It is well known that faces with direct gaze give more salient visual signals to observers than do faces with averted gaze; thus, faces with direct gaze are more likely to capture the spatial attention of observers compared with averted gaze (Senju & Johnson, 2009; Yokoyama, Ichibashi, Hongoh, & Kita, 2011). In a visual search task, faces with direct gaze among faces with averted gaze are detected faster and more accurately than faces with averted gaze among faces with direct gaze (Conty, Tijus, Hugueville, Coelho, & George, 2006; von Grunau & Anston, 1995). On the other hand, faces with averted gaze shift the observer’s spatial attention to the direction indicated by the averted gaze. In a gaze-cuing paradigm, observers can respond to a target more quickly when faces with averted gaze in the center of the display indicate a peripheral location of the upcoming target than when they do not (Friesen & Kingstone, 1998; Langton, Watt, & Bruce, 2000; Vecera & Rizzo, 2006; Yokoyama, Noguchi, & Kita, 2012). Therefore, faces with direct gaze capture the attention of observers, whereas faces with averted gaze shift the observer’s attention to the direction indicated by the averted gaze.

Because the processing of faces with direct and averted gaze are functionally different, the neural processing of these two types of gaze is dissociated in the brain. Neuroimaging studies indicate that the processing of faces with direct gaze is more closely associated with the fusiform gyrus, right superior temporal sulcus (STS), medial prefrontal cortex, and amygdala than the processing of faces with averted gaze (Calder et al., 2002; George, Driver, & Dolan, 2001; Kampe, Frith, & Frith, 2003; Kawashima et al., 1999; Pageler et al., 2003; Pelphrey, Viola, & McCarthy, 2004; Sato, Yoshikawa, Kochiyama, & Matsumura, 2004; Wicker, Perrett, Baron-Cohen, & Decety, 2003). In contrast, the processing of faces with averted gaze is related to the left STS and intraparietal sulcus (Hoffman & Haxby, 2000; Wicker, Michell, Henaff, & Decety, 1998). Hence, faces with direct and averted gaze are different not only regarding behavior, but also regarding how they are processed in the observer’s brain.

Regarding the unconscious perception of faces with direct gaze, Stein, Senju, Peelen, and Sterzer (2011) used continuous flash suppression (CFS) to examine whether faces with direct or averted gaze were more effectively processed without conscious awareness. Those authors used CFS to render facial images invisible at the beginning of the trials, and then ramped up the contrast of those images until participants were consciously aware of them. It was found that participants became aware of faces with direct
gaze faster than they became aware of faces with averted gaze. Therefore, the authors concluded that faces with direct gaze were effectively processed without conscious awareness, which implies that these faces gain preferential access to the conscious awareness of faces.

Although Stein et al. (2011) study suggested that invisible faces with direct gaze induced stronger neural responses compared with faces with averted gaze, little is known about the unconscious neural processing of faces with direct gaze in the brain. To address this, we used electroencephalography (EEG) and recorded event-related potentials (ERPs) evoked by images of faces with direct gaze rendered invisible through CFS. Our aim was to identify the neural correlate of increased sensitivity to invisible faces with direct gaze compared with averted gaze. The high temporal resolution of EEG enabled us to measure the speed at which the invisible gaze information reached different parts of the brain.

2. Experiment 1 (behavioral experiment)

Before performing the EEG experiments, we replicated the study of Stein et al. (2011) to confirm that the preferential processing of faces with direct gaze relative to averted gaze also occurred in our study.

2.1. Methods

2.1.1. Participants

Five participants (three men and two women; age range, 20–31 years) were recruited from the Psychology Department of Kobe University. Informed consent was received from each participant after the nature of the study had been explained. All participants had normal or corrected-to-normal acuity of vision and had no history of neurological diseases. All individuals were naïve to the purposes of this experiment. Approval for the experiment was obtained from the ethics committee of Kobe University, Japan.

2.1.2. Stimuli and procedure

Visual stimuli were displayed on a Sony MultiScan 17sf II 14.1 in. CRT display with a resolution of 1024 × 768 pixels. Displays and data collection were controlled with MATLAB using the Psychophysics toolbox (Brainard, 1997; Pelli, 1997) on a Dell Optiplex 360 computer running Microsoft Windows XP (refresh rate, 60 Hz).

To create dichoptic viewing, we presented stimuli at two different locations on the screen. Two white frames (6.1 × 6.1") were displayed side by side on the screen, with one frame presented to each eye. A mirror stereoscope fused stimuli at those two locations. We used four pictures of faces (two males and two females) from the ATR DB99 database (ATR-Promotions, Kyoto, Japan). The gaze direction of each pictured person was leftward, straight, and rightward. The overall luminance and contrast levels of all pictures were adjusted using MATLAB. After controlling the luminance and root mean square (RMS) contrast levels, we performed an analysis of variance (ANOVA), which indicated the absence of significant differences between direct-gaze, rightward-gaze, and leftward-gaze pictures regarding luminance levels ($F_{2,11} = 0.019, p = 0.9815, \text{ n.s.}$) or RMS contrast levels ($F_{2,11} = 0.500, p = 0.6224, \text{ n.s.}$). The mean and standard error values of luminance and RMS contrast are presented in Table 1A. Direct-gaze pictures were used for the direct-gaze condition, and leftward- and rightward-gaze pictures were used for the averted-gaze condition. In the averted-gaze condition, images of leftward gaze were positioned in the upper-left corner of the frame, whereas images of rightward gaze were positioned in the upper-right corner of the frame.

Table 1A. Mean and standard deviation of luminance and RMS contrast in Experiment 1 (behavioral experiment).

<table>
<thead>
<tr>
<th></th>
<th>Direct gaze</th>
<th>Rightward gaze</th>
<th>Leftward gaze</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminance</td>
<td>Mean (cd/m²)</td>
<td>s.d.</td>
<td>Mean (cd/m²)</td>
</tr>
<tr>
<td>RMS Contrast</td>
<td>Mean</td>
<td>s.d.</td>
<td>Mean</td>
</tr>
<tr>
<td>Direct gaze</td>
<td>14.350</td>
<td>0.555</td>
<td>14.425</td>
</tr>
<tr>
<td>Rightward gaze</td>
<td>5.000</td>
<td>0.000</td>
<td>4.997</td>
</tr>
</tbody>
</table>

The experiment used a one-factor repeated-measure design with two levels of gaze direction: direct and averted gaze. An experimental block consisted of 80 trials, in which the two conditions were intermixed randomly. Ten practice trials preceded the experimental trial.

Fig. 1A shows an example of a trial sequence. Each trial cycled a fixation display (1000 ms) as a preflash period; this was followed by the presentation of a rapid sequence of high-contrast colored Mondrian patterns at 20 Hz to the dominant eye of the participant. The colored Mondrian patterns were used as continuous flashes that rendered low-contrast images invisible (Noguchi, Yokoyama, Suzuki, Kita, & Kakigi, 2012; Stein, Peelen, & Sterzer, 2012; Tsuchiya & Koch, 2005). To determine eye dominance in participants, we used a variation of the Porta test (Roth, Lora, & Heilman, 2012); three participants had dominant right eyes. Conversely, a facial image was gradually introduced to the nondominant eye, and the contrast of the facial image was ramped up linearly from 0% to 100% over 1 s. Facial images appeared either at the upper-left or upper-right corner of the white frame. The continuous flashes and facial images were presented until participants responded, or for 10 s. Participants pressed the left or right key as quickly and accurately as possible when any part of the facial image became visible.

2.2. Results

Fig. 1B shows the mean reaction time of the two gaze-direction conditions. A t test analysis revealed the presence of a significant difference between the two conditions ($t_4 = -3.438, p = 0.05$). This result provides evidence that the preferential processing of faces with direct gaze, compared with faces with averted gaze, occurred in our study. Based on our behavioral results, we measured ERPs to investigate the neural mechanisms underpinning the enhanced sensitivity to process unconsciously faces with direct gaze.

3. Experiment 2 (EEG experiment)

3.1. Methods

The method described in Experiment 2 was similar to that used in Experiment 1, with the exception of the following details.

3.1.1. Participants

Twelve participants (nine men and three women; age range, 20–29 years) were recruited from the Psychology Department of Kobe University. Informed consent was received from each participant after the nature of the study had been explained. All participants had normal or corrected-to-normal acuity of vision and had no history of neurological diseases. All individuals were naïve to the purposes of this experiment. Approval for the experiment was obtained from the ethics committee of Kobe University, Japan.
responded to direct gaze more quickly than averted gaze. For high-contrast pictures, and absence of significant differences between direct-gaze, rightward-gaze, and leftward-gaze pictures regarding luminance levels ($F_{2,17}=0.065$, $p=0.9375$, n.s.) or RMS contrast levels ($F_{2,17}=1.519$, $p=0.2508$, n.s.) for high-contrast pictures, and absence of significant differences between direct-gaze, rightward-gaze, and leftward-gaze pictures regarding luminance levels ($F_{2,17}=0.207$, $p=0.8154$, n.s.) or RMS contrast levels ($F_{2,17}=0.341$, $p=0.7162$, n.s.) for low-contrast pictures.

### 3.1.2. Stimuli and procedure

We used six pictures (three men and three women) from the ATR DB99 database (ATR-Promotions, Kyoto, Japan), and gaze direction was leftward, straight, and rightward for each pictured person. To create visible and invisible conditions, we prepared high- and low-contrast pictures. The overall luminance and contrast levels of the pictures were adjusted using Adobe Photoshop 6.0 for both high- and low-contrast pictures. After controlling the luminance and RMS contrast levels, we performed ANOVA, which indicated the absence of significant differences between direct-gaze, rightward-gaze, and leftward-gaze pictures regarding luminance levels ($F_{2,17}=0.065$, $p=0.9375$, n.s.) or RMS contrast levels ($F_{2,17}=1.519$, $p=0.2508$, n.s.) for high-contrast pictures, and absence of significant differences between direct-gaze, rightward-gaze, and leftward-gaze pictures regarding luminance levels ($F_{2,17}=0.207$, $p=0.8154$, n.s.) or RMS contrast levels ($F_{2,17}=0.341$, $p=0.7162$, n.s.) for low-contrast pictures.

### 3.1.3. EEG measurement and data analysis

EEG was recorded from 19 scalp electrodes (FP1, FP2, F3, Fz, F4, F7, F8, C3, Cz, C4, T3, T4, T5, T6, P3, Pz, P4, O1, and O2) [EEG1200; Nihon Koden, Tokyo, Japan]. EEG was recorded continuously at a rate of 500 Hz and referenced with an average potential measured from the right and left earlobes. Neural activity in response to the facial images was examined by measuring visual-evoked potentials (VEPs) that were time locked to the onset of those images. We

<table>
<thead>
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<th>High-contrast pictures</th>
<th>Direct gaze</th>
<th>Rightward gaze</th>
<th>Leftward gaze</th>
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<tbody>
<tr>
<td>Luminance</td>
<td>26.528</td>
<td>26.542</td>
<td>26.590</td>
</tr>
<tr>
<td>Contrast (RMS)</td>
<td>14.564</td>
<td>14.558</td>
<td>14.604</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Low-contrast pictures</th>
<th>Direct gaze</th>
<th>Rightward gaze</th>
<th>Leftward gaze</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminance</td>
<td>8.780</td>
<td>8.735</td>
<td>8.690</td>
</tr>
<tr>
<td>Contrast (RMS)</td>
<td>1.525</td>
<td>1.518</td>
<td>1.511</td>
</tr>
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The mean and standard error values of the luminance and RMS contrast are presented in Table 1B.

Fig. 2 shows an example of a trial sequence. Each trial cycled through a fixation display (1000 ms) as a preflash period, followed by the presentation of a rapid sequence of high-contrast colored Mondrian patterns to the dominant eye of the participant. To determine eye dominance in participants, we used a variation of the Porta test (Roth et al., 2002). All participants had dominant right eyes. Each colored Mondrian pattern appeared for 50 ms, 26 different patterns were used in each trial, and the duration of the flash period was 1300 ms. Conversely, the images presented to the nondominant eye differed depending on seven types of trials that were intermixed randomly: high-contrast direct gaze, high-contrast rightward gaze, high-contrast leftward gaze, low-contrast direct gaze, low-contrast rightward gaze, low-contrast leftward gaze, and gray trials. Stimuli were presented to the dominant eye for 500 ms. In the high-contrast conditions, participants perceived the gaze direction of the target faces consciously because of the high luminance contrast of those images. In the low-contrast conditions, however, the luminance contrast of the facial images was too low for them to be perceived consciously under CFS. In the gray trials, no images were presented throughout the flash period. The duration of the presentation of all images to the nondominant eye was between 600 and 1100 ms after the onset of the continuous flashes; thus, neural responses to the facial images were not confounded with those induced by the onset of continuous flashes. Subsequently, we presented continuous flashes to the nondominant eye in the last 200 ms of each trial to prevent the perception of afterimages.

After the trials, participants were required to answer two questions sequentially. The first question probed target detection (subjective measurement): participants pressed one key when images were visible and another key when images were invisible. The second question probed the participants’ ability to identify accurately the gaze direction of facial images (objective measurement). Even if participants answered “no” to the first question, the second question was presented to exclude the possibility of the unconscious processing of invisible stimuli. An experimental block consisted of 84 trials in which the seven conditions (12 trials for each condition) were intermixed randomly. Six blocks were conducted.

| Table 1B. Mean and standard deviation of luminance and RMS contrast in high-contrast and low-contrast pictures in Experiment 2 (EEG experiment). |
|---------------------------------|-----------------|-----------------|-----------------|
|                                | Direct gaze     | Rightward gaze  | Leftward gaze   |
| **High-contrast pictures**      |                 |                 |                 |
| Luminance                       | 26.528          | 26.542          | 26.590          |
| Contrast (RMS)                  | 14.564          | 14.558          | 14.604          |
| **Low-contrast pictures**       |                 |                 |                 |
| Luminance                       | 8.780           | 8.735           | 8.690           |
| Contrast (RMS)                  | 1.525           | 1.518           | 1.511           |
performed one-way ANOVA to test for the presence of significant differences and false-alarm rates in the gray condition. There were no differences between detection rates in the low-contrast conditions and false-alarm rates in the gray condition, in which no facial image was presented. We performed one-way ANOVA to test for the presence of significant differences between detection rates in the low-contrast conditions and false-alarm rates in the gray condition. There were no significant differences between the low-contrast direct gaze, low-contrast rightward gaze, low-contrast leftward gaze, or gray condition ($F_{3,47} = 0.169$, $p = 0.9167$). Thus, the detection rates in the low-contrast conditions and false-alarm rates in the gray condition were not significantly different. These data indicate that participants could not consciously perceive the low-contrast images regardless of whether gaze direction was direct, rightward, or leftward. Subsequently, we used a gaze direction discrimination task to confirm that the low-contrast images were invisible to participants (Fig. 3B). The accuracy of the high-contrast condition was almost 100% (98.3 ± 0.1%), which was significantly higher ($t_{11} = 190.1$, $p < 0.001$) than the chance level (33.3%). In contrast, the accuracy of the low-contrast condition was 34.3 ± 1.8%, which was not significantly different from the chance level ($t_{11} = 0.34$, $p = 0.73$). To test that observers were not able to discriminate the gaze direction of facial images in the low-contrast conditions, we performed ANOVA to compare the three low-contrast conditions and found no significant differences between the three conditions ($F_{2,35} = 1.194$, $p = 0.321$). The results of tasks 1 and 2 suggest that the CFS blocked the conscious perception of the low-contrast facial images, whereas the high-contrast facial images broke the CFS and were processed consciously.

3.2. Results

3.2.1. Behavioral data

Fig. 3A shows the behavioral results of task 1 (detection task) averaged across the 12 participants. The mean ($±$ SE across participants) detection rates for the high-contrast pictures were 99.7 ± 0.2% (high-contrast direct gaze), 98.1 ± 0.3% (high-contrast rightward gaze), and 99.6 ± 0.3% (high-contrast leftward gaze). This result indicates that participants were able to detect the high-contrast facial images even during CFS. Conversely, the detection rates for the low-contrast pictures were 0.9 ± 0.5% (low-contrast direct gaze), 0.9 ± 0.4% (low-contrast rightward gaze), and 0.7 ± 0.3% (low-contrast leftward gaze), which were comparable to the false-alarm rates recorded in the gray condition (0.7 ± 0.3%), in which no facial image was presented. We performed one-way ANOVA to test for the presence of significant differences between detection rates in the low-contrast conditions and false-alarm rates in the gray condition. There were no significant differences between the low-contrast direct gaze, low-contrast rightward gaze, low-contrast leftward gaze, or gray condition ($F_{3,47} = 0.169$, $p = 0.9167$). Thus, the detection rates in the low-contrast conditions and false-alarm rates in the gray condition were not significantly different. These data indicate that participants could not consciously perceive the low-contrast images regardless of whether gaze direction was direct, rightward, or leftward. Subsequently, we used a gaze direction discrimination task to confirm that the low-contrast images were invisible to participants (Fig. 3B). The accuracy of the high-contrast condition was almost 100% (98.3 ± 0.1%), which was significantly higher ($t_{11} = 190.1$, $p < 0.001$) than the chance level (33.3%). In contrast, the accuracy of the low-contrast condition was 34.3 ± 1.8%, which was not significantly different from the chance level ($t_{11} = 0.34$, $p = 0.73$). To test that observers were not able to discriminate the gaze direction of facial images in the low-contrast conditions, we performed ANOVA to compare the three low-contrast conditions and found no significant differences between the three conditions ($F_{2,35} = 1.194$, $p = 0.321$). The results of tasks 1 and 2 suggest that the CFS blocked the conscious perception of the low-contrast facial images, whereas the high-contrast facial images broke the CFS and were processed consciously.

![Fig. 2. An example of the sequence of events in a typical trial. Two different images were presented to the dominant and nondominant eyes of participants and a mirror stereoscope fused those images. After the presentation of a fixation screen for 1 s, continuous flashes of 20 Hz were given to the dominant eye, which rendered a target facial image invisible to the nondominant eye. After presentation of continuous flashes, participants were required to perform two tasks: detection and discrimination tasks.](image-url)
3.2.2. VEP waveforms

Because no facial images were presented in the gray condition, the ERPs induced by the gray condition should reflect neural responses to continuous flashes, not faces. To isolate the ERP components related to gaze perception, we subtracted EEG waveforms in the gray condition from those of the other gaze conditions. We separated the high-contrast conditions from the low-contrast conditions to investigate VEPs from the 19 points on each participant’s scalp. Fig. 4 shows the grand-averaged VEPs at all 19 electrodes for the high-contrast conditions, and Fig. 5 shows the grand-averaged VEPs at all 19 electrodes for the low-contrast conditions. Some studies have suggested that, compared with faces with averted gaze, faces with direct gaze elicit a larger N1 in the posterior channels, such as O1, O2, T5, and T6 (Conty, N'Diaye, Tijus, & George, 2007; Pesciarelli, Sarlo, & Leo, 2011) when the two types of gaze are presented consciously. Thus, we averaged the EEG waveforms in the high-contrast conditions across the four electrodes listed above, and applied one-factorial repeated-measures ANOVA to the averaged ERP amplitude within a 150–230 ms latency range (Taylor, George, & Ducorps, 2001). This analysis revealed an absence of significant main effects between the three conditions ($F_{2,35} = 0.353, p = 0.7068$). In contrast, regarding the unconscious processing of face stimuli, previous studies reported a negative deflection of EEG signals to faces presented unconsciously between 200 and 300 ms after stimulus onset (Liddell, Williams, Rathjen, Shevrin, & Gordon, 2004). Consistent with this report, we observed in some electrodes that the ERP components of the low-contrast rightward- and leftward-gaze conditions at 200–300 ms. To analyze these components selective to direct gaze statistically, we first averaged the data of the low-contrast rightward- and leftward-gaze conditions, making ERPs in the averted-gaze condition as a control. Subsequently, we performed a t test analysis at each channel to explore which channels exhibited significant differences between direct and averted gaze in the invisible conditions. There were significant differences between direct and averted gaze at F4 ($t_{11} = -2.23; p < 0.05$), C4 ($t_{11} = -2.46; p < 0.05$), Fz ($t_{11} = -2.25; p < 0.05$), and Cz ($t_{11} = -2.26; p < 0.05$) (see gray-shaded windows in Fig. 5). The responses at those electrodes are enlarged in Fig. 6A. We then created 50 ms time windows (Fig. 6B) and performed 2 (direct/averted: gaze direction) × 4 (channel) × 8 (time window) repeated-measures ANOVA. We found significant main effects of gaze direction and time window ($F_{1,74} = 11.545, p < 0.001$ for gaze direction; $F_{2,74} = 3.661, p < 0.001$ for time window), but not of channel ($F_{1,74} = 0.171, p = 0.916$). The interaction between gaze direction and time window was significant ($F_{2,74} = 2.109, p < 0.05$); however, we did not find a significant interaction between gaze direction and channel ($F_{2,74} = 0.426, p = 0.735$) or between channel and time window ($F_{2,74} = 0.180, p = 1.000$). Because the main effects of channel and interactions including channel were not significant, we factored out the effects of channel and performed two-way ANOVA (gaze direction and time window). There were significant main effects of gaze direction ($F_{1,74} = 11.889, p < 0.001$) and time window ($F_{2,74} = 3.770, p < 0.001$), and a significant interaction between gaze direction and time window ($F_{2,74} = 2.172, p < 0.05$). To examine which of the time windows exhibited significant differences between direct and averted gaze, we performed a post hoc analysis of interaction using a Bonferroni correction. There were significant differences between direct and averted gaze at time windows of 200 ms (corrected $p < 0.005$), 250 ms (corrected $p < 0.001$), and 350 ms (corrected $p < 0.05$) (Fig. 6C).
4. Discussion

This study was the first to investigate the neural correlate of increased sensitivity to the unconscious processing of faces with direct gaze. We recorded EEG during CFS to address this question. The effect of the unconscious perception of faces with direct gaze appeared at time windows of 200, 250, and 350 ms after stimulus onset at the parietofrontal electrodes. No specific neural responses to invisible faces with direct gaze were observed at the occipital or temporal electrodes, which might be consistent with previous findings reporting a lack of aftereffects induced by invisible faces with direct gaze (Stein et al., 2012). Taken together, our findings suggest that faces with direct gaze are processed effectively under an unconscious condition, and that this effect occurs 200, 250, and 350 ms after the unconscious representation of faces with direct gaze.

Previous studies found large negative deflection at 200–300 ms at the parietofrontal electrodes when fearful faces were presented subliminally (Kiss & Eimer, 2008; Liddell et al., 2004). The large EEG waveforms observed in these studies are similar to our waveform data of faces with direct gaze. Given that the presentation of fearful faces and faces with direct gaze evokes emotional responses in observers (Pessoa & Adolphs, 2010; Senju & Johnson, 2009), the EEG components of 200–300 ms in response to faces with direct gaze observed in the present study might reflect unconscious emotional responses. Our data clearly demonstrated a latency of the processing of unconscious faces with direct gaze, but did not reveal the brain regions that were related to the processing; thus, additional neuroimaging studies are necessary to elucidate the specific brain regions that are mainly associated with the processing unconscious faces with direct gaze.

Why did we obtain differential responses to direct vs. averted gaze in the invisible condition only? One possibility is the involvement of feedback neural signals that are uniquely induced by visible stimuli. Feedback neural signals are neural activations that are essential for visual awareness (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Lamme, 2003). Although the conscious perception of visual stimuli evokes brain responses that are distributed widely across the entire brain, those strong responses sometimes mask subtle differences among conditions. For instance, Jiang and He (2006) used functional magnetic resonance imaging to compare the neural responses to neutral and fearful faces that were either visible or rendered invisible by CFS. In the visible (no CFS) condition, those authors found significant hemodynamic responses in the STS to both neutral and fearful faces. In contrast, under the invisible condition, the same STS region indicated a significant response only to fearful faces. Because the fusiform face area (FFA) was similarly activated by the invisible neutral and fearful faces, the overall result obtained in the invisible condition indicates a clear functional distinction between the FFA (structural encoding) and STS (expressional or emotional analyses). Jiang and He (2006) concluded that this clear distinction was caused by an absence of awareness of facial information, which minimized the cortical responses associated with the conscious perception of faces.

We suggest that significant responses to invisible faces with direct compared with averted gaze can be explained by a lack of consciousness-related activity under unconscious conditions. In fact, the results of previous neurophysiological studies that investigated the effect of visible direct and averted gaze are inconsistent. Some studies have suggested that faces with direct gaze evoked larger VEPs than did faces with averted gaze (Conty et al.,
2007; Senju, Tojo, Yaguchi, and Hasegawa, 2005), whereas other studies found the opposite effects (Puce, Smith, & Allison, 2000; Watanabe, Miki, & Kakigi, 2002). Another group found no differences between VEPs in response to faces with direct and averted gaze (Taylor, George, & Ducorps, 2001). The inconsistency between previous results may be attributable to the consciousness-related neural activity induced by visible gaze, which may have masked the small differences between the direct- and averted-gaze conditions. Eliminating the feedback process, therefore, might enable us to identify the distinct processing of faces with direct and averted gaze using EEG.

In conclusion, we demonstrated the existence of a neural correlate of increased sensitivity to the unconscious processing of faces with direct gaze. This effect was observed 200, 250, and 350 ms after stimulus presentation. The results of our study are consistent with those of a previous behavioral study that indicated

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**Fig. 6.** EEG waveforms and time sequence at four channels. (A) EEG waveforms of direct gaze and averted gaze. Averted-gaze data were created by averaging low-contrast rightward and leftward gaze data. (B) Mean amplitude of EEG responses over time. EEG waveforms from 0 to 400 ms were divided into eight time windows of 50 ms and the mean amplitude within each time window was plotted as a function of time. (C) Average across four channels in panel B. Amplitude of direct gaze was more negatively deflected than amplitude of averted gaze at time-window of 200, 250, and 350 ms after stimulus onset (*p < .05, **p < .005, ***p < .001).
that the visual information of faces with direct gaze reached visual awareness faster than that of faces with averted gaze. We believe that the current study will provide important clues for the elucidation of the neural mechanism underlying the processing of faces with direct gaze.

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