Perception of illusory shift of gaze direction by infants

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\textbf{Abstract}

Detection of others' gaze direction is an essential tool in everyday communication. As the gaze direction is analyzed rapidly and automatically, we hardly notice how we are performing this task. Wollaston's illusion [Wollaston, W. H. (1824). On the apparent direction of eye in a portrait. \textit{Philosophical Transactions of the Royal Society of London Series B, 114}, 247–256] provides us the chance to understand an aspect of this problem, in which the change in orientation of the face results in the shift of the perceived gaze direction. This illusion suggests that we analyze others' gaze directions by integrating information from eyes and that from face. By using Wollaston's illusion, we examined how 6- to 8-month-old infants process gaze direction in upright and inverted faces. Our results suggest that 8-month-olds process gaze direction in terms of the orientation of the face, and perceive an illusory shift of the gaze direction in Wollaston's illusion when the face was shown in an upright orientation.

\section{1. Introduction}

Detection of others' gaze direction is an essential tool in everyday communication. Recent developmental studies suggest that even young infants are sensitive to others' gaze direction and that mutual gaze, where people looking at each other's eyes, has a special status for humans from birth (e.g. Farroni, Csibra, & Johnson, 2004; Farroni, Csibra, Simion, & Johnson, 2002). Farroni et al. (2002) reported that newborn infants preferentially look at a face whose gaze direction is looking toward them (direct gaze), rather than a face whose gaze direction is looking away from them (averted gaze). Similarly, 3-month-olds smile more at a face with direct gaze rather than a face with averted gaze, a gaze looking away from a perceiver (Hains & Muir, 1996; Symons, Hains, & Muir, 1998). Interestingly, the mutual gaze seems to have a facilitative effect on infants' learning of faces.

Bliss and Camp (2001) reported that 9 and 12 weeks old infants preferred the experimenter's face to the novel face after the experimenter delivered a sucrose solution to the infants with mutual gaze. However, no preference was observed after the delivery of sucrose without mutual gaze to infants. The results suggest that gaze direction play some role in infants face recognition. Further, Farroni, Massaccesi, Menon, and Johnson (2007) provided more direct evidence that direct gaze enhanced processing of faces in infants. They found that 4 months showed better recognition memory for faces when they learned a face in the direct gaze condition than in the averted gaze condition.

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Fig. 1. Stimuli used in the upright condition (top), and magnifications of their eyes part (bottom). The familiarization face (a), Head and Eyes Reversed face (b), and Head Alone Reversed face (c). Upside-down stimuli were used in the inverted condition.

Similar interaction between gaze direction and face recognition has been found in electrophysiological studies. By recording ERP (event-related potentials) responses, Farroni et al. (2002) examined infants’ processing of gaze direction when the infants looked at faces with direct and averted gazes. They found that a face-sensitive component of infant ERP, “infant N170”, differed between direct and averted gazes. Specifically, the amplitude of “infant N170” was greater in faces presented with direct rather than averted gazes. Farroni et al. (2004) further found the same difference in the ERP activity between direct and averted gazes in the orientation of an averted face, while this difference disappeared when the faces were inverted. These results suggested that infants could detect gaze direction irrespective of the orientation of the face as long as the face was upright.

Different from the developmental studies, several studies with adults showed that orientation of the faces have some effect on the perceived gaze direction. Wollaston (1824) produced a dramatic illusion (Fig. 1) in which a change in the orientation of the face results in a shift in the perceived gaze direction even though the eyes themselves remained unchanged. Wollaston’s illusion demonstrates that the perceived direction of the gaze does not exclusively depend on the position of the iris and pupil relative to the sclera. Rather, adults process gaze direction configurally in relation to the other features of the face. Psychophysical studies provided further evidences of configural processing of gaze direction in adults, and found that the configural processing of gaze direction is reduced by facial inversion (Maruyama & Endo, 1983; Langton, Honeyman, & Tessler, 2004). Using schematic face image, Maruyama and Endo (1983) reported that the illusory shift of gaze direction occurred by displacing the eyes to the left or right within a head outline in the upright face orientation, but this illusion was markedly reduced when the face was inverted. More recently, Langton et al. (2004) used realistic images of faces with brief presentation duration to test the effects of inverting the face on the illusory shift of gaze direction. Langton et al. (2004) reported that the effect of head context on the perceived gaze direction persisted even when the faces were shown in the inverted condition but the influence of nose angle on the perceived gaze direction disappeared under inverted conditions.

By using Wollaston’s illusion, we examined the development of configural processing of gaze direction. Previous studies on the development of face perception showed that 7- to 8-month-old infants process face configurally based on the relation of facial features when faces were upright (Cohen & Cashon, 2001; Schwarzer & Zauner, 2003), while they process faces analytically based on facial features when faces were inverted (Cohen & Cashon, 2001). That is, the infants processed the relationship between the facial features in the upright face condition, but they processed each facial features independently in the inverted face condition.

In Cohen and Cashon (2001), infants were habituated to two female faces. After the habituation, infants were tested on a familiar face, a switched face which was created by combining features from the two habituated faces, and a novel face. Cohen and Cashon (2001) reasoned that if infants analytically processed individual facial features, the switched face should not look novel to them relative to the familiar face, because the features were derived from the habituated faces. If, however, infants processed the relationship among facial features, the switched face should look novel because it is a new configuration composed of the familiar features. In the upright condition, infants looked longer at the composite (switched) face than at the familiar face, whereas in the inverted condition infants did not. These patterns of results were taken as an evidence of configural processing of upright faces, and the disruption of configural processing (i.e. process features independently) for the inverted faces.

While Cohen and Cashon (2001) combined all the internal features with external features to create the switch face, Schwarzer and Zauner (2003) exchanged only single internal feature (eye/mouth) to create the switch face. Schwarzer and Zauner (2003) found that 8-month-olds looked longer at the switched face in which either eyes or mouth has been exchanged
than at the familiar face. The results suggest that 8-month-olds process both eyes and mouth configurally in relation to other facial features.

Considering the previous studies showing close interaction between the processing of faces and perception of gaze direction (Farroni et al., 2002, 2004, 2007), we hypothesized that configural processing of gaze direction develops along with the development of configural processing of faces. In the present study, we tested this possibility by using Wollaston’s illusion. Specifically, we tested whether 6- to 8-month-olds process gaze direction in the upright and the inverted face configurally or analytically.

2. Experiment 1

The purpose of Experiment 1 was to investigate whether the infants could process gaze direction configurally, including the direction of the eyes and the orientation of the face. For this purpose, we tested whether infants perceive the Wollaston’s illusion as adults do.

A familiarization/novelty preference procedure was used to assess infants’ processing of gaze direction. In this procedure, infants were first familiarized with a stimulus by being exposed to it repeatedly. After familiarization, infants were shown a pair of stimuli in test trials. The preferential looking behavior observed in test trials indicates which of the two test stimuli was perceived as novel by the infants. Generally, infants preferentially look at novel stimuli (novelty preference).

In the present study, infants were first familiarized with the face shown in Fig. 1(a). After familiarization, they were tested with the pair of faces shown in Fig. 1(b) and (c). The two types of test faces were produced by mirror imaging the familiarization face entirely (b: Head and Eyes Reversed face) or partially except for the eyes (c: Head Alone Reversed face).

For adults who process gaze direction configurally with the orientation of the face and perceive the Wollaston’s illusion, both familiarization face and the Head and Eyes Reversed face are perceived to have an averted gaze, while the Head Alone Reversed face to have a direct gaze. Although the familiarization face and the Head and Eyes Reversed face are perceived to look at different directions, they are both categorized as a face with averted gaze. Considering that infants preferentially look at face with direct gaze from averted gaze, we assumed that the categorical change from averted gaze to direct gaze show a novelty preference over the change between the averted gaze. Therefore, if infants process gaze direction configurally and perceive the illusory shift of gaze direction in the Wollaston’s illusion as adults do, they are expected to show novelty preference for the Head Alone Reversed face.

If infants process gaze direction analytically regardless of the contextual head orientation, however, both familiarization face and the Head Alone Reversed face are perceived to have an averted gaze. In contrast, the Head and Eyes Reversed face is perceived to have a direct gaze. Therefore, if infants process gaze direction analytically, they would show novelty preference for the Head and Eyes Reversed face over the Head Alone Reversed face.

2.1. Methods

2.1.1. Participants

The final sample consisted of 16 6-month-olds (6 female and 10 male, mean age = 176.81 days, ranging from 165 to 193 days), 16 7-month-olds (7 female and 9 male, mean age = 213 days, ranging from 196 to 223 days), and 16 8-months (7 female and 9 male, mean age = 240.18 days, ranging from 226 to 255 days). An additional 35 infants were tested but were excluded from the analysis due to fussiness (3), side bias greater than 90% (10), longer looking times in the last than in the first three trials in the familiarization phase (10), or due to looking times over the two test trials that were less than 10 s (12).

2.1.2. Apparatus and stimuli

Stimuli were produced by adding the explicit contour of the face line to Wollaston’s original configuration (Fig. 1(a)) and by appropriately mirror reversing the image in part or whole (Fig. 1(b) and (c)). The stimulus faces were subtended roughly 17° vertically and were drawn against a uniform white background. They were displayed as pairs side by side on a 21-in. CRT monitor. The distance between the left and right stimuli was 11°. The infants’ viewing distance was approximately 40 cm. There was a CCD camera just below the monitor screen. Throughout the experiment, the infants’ behavior was videotaped by this camera. The experimenter could observe their behavior via a TV monitor connected to the CCD camera.

2.1.3. Procedure

A familiarization/novelty preference procedure was used to assess infant’s processing of gaze direction. Infants were first exposed to the familiarization face (Fig. 1(a)) repeatedly in six familiarization trials, in which an identical familiarization face was shown as a pair side by side. Each familiarization trial was terminated if the infant looked away from the CRT monitor for at least 3 s or when the trial had lasted for 20 s. After the familiarization trials, infants were shown the Head and Eyes Reversed face (Fig. 1(b)) and the Head Alone Reversed face (Fig. 1(c)) in two 15 s test trials. Both faces were presented at the same time as a pair, side by side. The position of the two faces was reversed between the two trials. One observer, who was unaware of the identity of the stimulus, measured the infants’ fixations to the left and right sides of the display based on video recordings. The video recordings only showed the infant’s looking behavior.
Table 1
The average looking time (s) on 6-, 7-, and 8-month-olds during the first three trials and the last three trials on six familiarization trials in Experiments 1 and 2.

<table>
<thead>
<tr>
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<th>Experiment 1</th>
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<th>Experiment 2</th>
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<td>First three trials</td>
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<td>First three trials</td>
<td>Last three trials</td>
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<tr>
<td>6-month-olds (SE)</td>
<td>9.70 (0.65)</td>
<td>6.60 (0.78)</td>
<td>14.83 (0.90)</td>
<td>9.76 (1.01)</td>
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<tr>
<td>7-month-olds (SE)</td>
<td>11.27 (0.56)</td>
<td>8.88 (0.74)</td>
<td>13.69 (0.82)</td>
<td>11.80 (0.84)</td>
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<tr>
<td>8-month-olds (SE)</td>
<td>11.65 (0.53)</td>
<td>8.16 (0.60)</td>
<td>13.57 (0.64)</td>
<td>8.87 (0.74)</td>
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</table>

2.2. Results and discussion

Firstly, we conducted an analysis of the familiarization trials. Table 1 shows the looking times of infants during the familiarization trials. A three-way ANOVA with trial (first three, last three) as a repeated factor, and sex (male, female), age (6 months, 7 months, 8 months) as the between-subject factors on the look durations during familiarization showed a main effect of trial ($F(1,42) = 92.02$, $p < .001$). No other main effects or interactions reached significance. The results show that infants habituated to the familiarization face to some degree.

Secondly, we calculated an individual preference score for the Head Alone Reversed face. The preference scores were calculated by dividing the infants’ looking time for the Head Alone Reversed face during the two test trials by the total looking time over the two test trials, and then multiplying this ratio by 100. Fig. 2 (left panel) shows the infants’ novelty preference scores for the Head Alone Reversed face.

As our main interest was to see whether infants at each age look longer one of the test stimuli over the other, we conducted $t$-test vs. chance level (with Bonferroni correction) on the preference score of each age group. Two-tailed one-sample $t$-tests (vs. a chance level of 50%) revealed that 8-month-olds showed a significant novelty preference for the Head Alone Reversed face ($t(15) = 5.29$, $p < .01$). By contrast, 6- and 7-month-olds showed no significant preference for either face (6-month-olds: $t(15) = 0.31$, $p = .76$; 7-month-olds: $t(15) = 1.24$, $p = .23$). The results of this experiment showed that only 8-month-olds perceived the Wollaston’s illusion and discriminated the difference between averted and direct gaze. The results of age related difference were confirmed by ANOVA. A two-way ANOVA with sex (male, female), age (6 months, 7 months, 8 months) as the between-subject factors on the preference score revealed only the main effect of age ($F(1,42) = 3.66$, $p < .05$). No other effect or interaction reached significance. These results suggest that only the 8-month-olds process gaze direction configurally taking into account the direction of the eyes and the orientation of the face.

Given that infants prefer to look at a direct gaze to a averted gaze (Farroni et al., 2002), one might argue that the preference found for stimulus C is actually a preference for a direct gaze rather than a novelty preference. However, we think the preference found in this experiment is a novelty preference, as infants did not show any preference when we measured a spontaneous preference between stimulus C and stimulus B in the preliminary experiment. Further, even in the case that the

Fig. 2. Mean preference score for the Head Alone Reversed face during test trials. Each bar shows the mean preference score. The vertical axis depicts age of the infants in months, and the horizontal axis depicts the novelty preference. The error bars show standard deviations. The left panel shows the results from the upright condition (Experiment 1) and the right panel shows those from the inverted condition (Experiment 2).
preference for stimulus C was actually a preference for a direct gaze, it will not change our interpretation that 8-month-olds process gaze direction in a configural manner. It is because the perception of a direct gaze in stimulus C occurs only when one process gaze direction configurally.

3. Experiment 2

The results of Experiment 1 indicated that only 8-month-olds process gaze direction configurally and perceive the illusory shift of gaze direction in the Wollaston’s illusion. It is well known that simple inversion of the face disrupts the configural processing of faces (Valentine, 1988; Yin, 1969). Thus, when a face is inverted, the face is processed analytically. If configural processing of gaze direction depends on the mechanism that allows configural processing of face, we can expect facial inversion would disrupt or reduce the illusory gaze shift in the Wollaston’s illusion.

In the present experiment, we presented the stimuli used in Experiment 1 upside down. Infants were familiarized with the face shown in Fig. 1(a), and then tested their preference between the Head and Eyes Reversed face and Head Alone Reversed face. As in Experiment 1, a novelty preference for the Head Alone Reversed face indicates the configural processing of gaze direction while a novelty preference for the Head and Eyes Reversed face indicates the analytical processing of gaze direction.

3.1. Methods

3.1.1. Participants

The final sample consisted of 16 6-month-olds (8 female and 8 male, mean age = 177 days, ranging from 165 to 191 days), 16 7-month-olds (6 female and 10 male, 4 female and 12 female, mean age = 207.875 days, ranging from 195 to 224 days), and 16 8-months (8 female and 8 male, mean age = 238.5 days, ranging from 227 to 253 days).

An additional of 33 infants were tested but were excluded from the analysis due to fussiness (4), side bias greater than 90% (4), longer looking times in the first than the last three trials of the familiarization (14), or due to looking times time over the two test trials that were less than 10 s (11).

3.1.2. Apparatus and stimuli

Apparatus and stimuli were identical to those described in Experiment 1 except that the images were turned upside down.

3.1.3. Procedure

Procedure was the same as that of Experiment 1.

3.2. Results and discussion

The analysis of the familiarization trials in Experiment 2 was conducted in the same way as in Experiment 1. Table 1 shows the looking times of infants during the familiarization trials. A three-way ANOVA with trial (first three, last three) as an repeated factor, and sex (male, female), age (6 months, 7 months, 8 months) as the between-subject factors on the look durations during familiarization showed a main effect of trial ($F(1,42) = 137.02, p < .01$) and interaction between trial and age ($F(1,42) = 10.07, p < .01$). Post hoc analysis revealed a significant difference between the first three and last three trials for 6- and 8-month-olds ($p < .01$, HSD), and marginally significant difference for 7-month-olds ($p = .052$). No other main effects or interactions reached significance. The results show that infants habituated to the familiarization face to some degree.

Secondly, we calculated an individual preference score for the Head Alone Reversed face as in Experiment 1. Fig. 2 (right panel) shows the infants’ novelty preference scores for the Head Alone Reversed face in the inverted condition. Two-tailed one-sample $t$-tests (vs. a chance level of 50%) revealed that 8-month-olds showed a significant novelty preference for the Head and Eyes Reversed face ($t(15) = 4.98, p < .01$). By contrast, 6- and 7-month-olds showed no significant preference for either of the faces (6-month-olds: $t(15) = 0.35, p = .73$; 7-month-olds: $t(15) = 1.89, p = .08$). The results of age related difference were again confirmed by ANOVA. A two-way ANOVA with sex (male, female), age (6 months, 7 months, 8 months) as the between-subject factors on the preference score revealed only the main effect of age ($F(1,42) = 4.97, p < .05$). No other effect or interaction reached significance.

We conducted a two-way ANOVA of Experiment (Experiment 1/Experiment 2) × Age (6 months/7 months/8 months) on the novelty preference scores. This revealed a significant main effect of Experiment ($F(1,90) = 22.122, p < .01$) and Experiment × Age interaction ($F(2,90) = 8.34, p < .01$). Post hoc Tukey’s HSD tests revealed that only 8-month-olds showed significantly greater preference for the Head Alone Reversed face in Experiment 1 than in Experiment 2 ($p < .01$).

Different from Experiment 1, 8-month-olds in Experiment 2 showed a novelty preference for Head and Eyes Reversed face, suggesting that they processed gaze direction analytically rather than configurally when face was inverted. This is consistent with previous studies showing that facial inversion disrupt the configural processing of face in infants (Cohen & Cashon, 2001) as well as in adults (Valentine, 1988; Yin, 1969).
4. General discussion

Our results demonstrate that 8-month-olds but not 6- and 7-month-olds perceive Wollaston’s illusion in the same way as adults do. Our 8-month-olds behaved as if they perceived an illusory shift in the gaze direction in the Wollaston’s illusion when the face was upright (Experiment 1). That is, they responded to and preferred the categorical change in the gaze direction (from an averted gaze in the familiarization face to a direct gaze). When the face was inverted (Experiment 2), by contrast, 8-month-olds responded to the Head and Eyes Reversed face that would be perceived as the direct gaze, when they looked at only the eyes locally and the gaze direction would be processed analytically.

The perception of Wollaston’s illusion required not only the processing of the position of the iris and pupil relative to the sclera, but also that of the eyes relative to the other features of the face. Therefore, our results that 8-month-olds perceived Wollaston’s illusion suggest that 8-month-olds process gaze direction configurally in the case of upright faces.

The development of the perception of a person’s looking direction shown here coincides with the development of configural face processing shown in previous studies (Cohen & Cashon, 2001; Schwarzer & Zauner, 2003). Cohen and Cashon (2001) showed that 7-month-olds processed photo images of upright face configurally (Cohen & Cashon, 2001). Interestingly, Schwarzer and Zauner (2003) reported that 8-month-olds infants, but not 7-month-olds, processed upright face configurally when they tested infants’ face recognition using line drawing images (Schwarzer & Zauner, 2003). Considering that our stimuli were line drawing of faces, our results regarding the ability of 8-month-old infants to perceive gaze direction fits with the previous face study using line drawing face images.

To investigate the trend of the preference rate in different ages in the present study, we indicate the preference for the Head Alone Reversed face in the upright condition as a function of infants’ age as shown in Fig. 3. Although some infants at 6 and 7 months showed a preference for the Head Alone Reversed face, others preferred for the Head and Eyes Reversed face. By contrast, infants at 8 months consistently showed the preference for the Head Alone Reversed face.

From both results of Experiments 1 and 2 as well as Fig. 3, our findings demonstrated that only 8-month-olds showed novelty preferences consistently, whereas 6- and 7-month-olds did not show any preference. Given the results of null preference, it is difficult to speculate how 6- and 7-month-olds process gaze direction. However, from point of view of the developmental change on face processing, we speculate that as younger as 8-month-old is mature to process gaze direction configurally.

Cohen and Cashon (2001) demonstrated that 7-month-olds process upright faces configurally. Additionally, one electrophysiological study proposed that 8-month-olds have an ability to process a face configurally like adults (Scott & Nelson, 2006). These results suggest that it remains possible that infants aged over 7 months might have an ability to process faces configurally. Although our results indicated the absence of the novelty preferences in 7-month-old infants, we assume that the ability to process configural information would be developed as infants grow up, and the configural processing on face recognition as well as gaze direction in infants might become more stable at 8 months.

The coincidence between the processing of face and gaze direction is consistent with the recent proposal that gaze processing overlaps to a large degree with face processing in early infant development (Farroni et al., 2004). Similarly, Vecera and Johnson (1995) have suggested that there is some overlap between the ability to perceive the gaze from line drawing faces and to detect the faces, and these abilities are based on the same cortical mechanisms early in development. Consistent with these views, we provided further evidence that there is a similar developmental trend between the perception of face and perception of another person’s looking direction in terms of configural processing.
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Contributions. YO, SK, MKY, and MT designed the experiment. HK collected the data, and performed the statistical analysis. EN and YO drafted the manuscript. SK, MKY, and MT helped in drafting the paper and in considering the discussion of the results. All authors read and approved the final manuscript.

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