Infant learning ability for recognizing artificially produced three-dimensional faces and objects

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This study investigated infants’ ability to learn artificially produced three-dimensional faces and non-face objects by using the three-dimensional graphic software. We created three-dimensional faces and non-face objects that contained no texture or fixed light source and used a familiarization–novelty preference procedure to familiarize infants with multiple views of a face or a shoe (non-face object). We set two familiarization presentations: one of sequentially rotating images of a single object (rotating presentation) and another of 6 different static view images (static presentation). After familiarization, we checked infants’ recognition of the learning objects between these conditions. In Experiment 1, we examined the infants’ ability to learn face and non-face objects in static and rotating presentations. Results showed that 6- to 8-month-old infants could learn the non-face objects in both presentations, while they could not learn the faces in the rotating presentation. In Experiments 2 and 3, we modified the rotating presentation for face learning. In Experiment 2, we used three-quarter views at test. In Experiment 3, we set a slower speed rotation. However, the infants still could not learn the faces. These results showed that infants’ ability to learn faces differs from their ability to learn non-face objects.

Keywords: rigid motion, view invariance, infant, three-dimensional face


Introduction

Experience of objects seen from various viewpoints may play an important role in viewpoint invariance in infants. Infants’ ability to learn three-dimensional objects has been demonstrated by Kellman. His early research showed that 3- to 5-month-old infants could discriminate familiar objects in novel axes of rotation from novel objects (Kellman, 1984). The infants in these experiments showed an ability to generalize three-dimensional form after habituation to a moving observer but only if the motion was continuous. They failed to generalize three-dimensional form across views within static displays (Kellman & Short, 1987). According to these studies, infants around these ages had acquired only some invariant three-dimensional object recognition ability.

In adult three-dimensional face recognition studies, it is well known that face learning is enhanced by viewing rotating faces (Pike, Kemp, Towell, & Phillips, 1997). Pike et al. showed that adults learn better from dynamic displays of heads rigidly rotating over 360 deg than from static images taken from multiple viewpoints. In infants’ face perception, facial motion promotes young infants’ recognition of unfamiliar faces (Otsuka et al., 2009).

Otsuka et al. compared 3- to 4-month-olds’ recognition of previously unfamiliar faces learned in a motion condition or a static condition. Infants viewing faces in the motion condition showed successful recognition with only 30-s familiarization even when presented with novel images at test. In contrast, infants viewing faces in the static condition showed successful recognition only when the familiarization duration was extended to 90 s and the same image was presented at test. Otsuka et al. used facial expressions with non-rigid facial movement. However, rigid facial movement might not promote three-dimensional face recognition in infants. For learning in static pose presentation, Fagan (1972) showed that 7-month-old infants could generalize a particular person’s face from multiple views. He examined whether infants discriminate between learned and novel human faces in three-quarter or profile views after frontal view presentation. Fagan found that 7-month-old infants could identify a learned face, despite the changing views. On the contrary, rigid facial movement (that is, rotating face) did not enhance three-dimensional face learning. Nakato, Kanazawa, and Yamaguchi (2010) examined whether infants discriminate between learned and novel human faces after a sequentially rotated face presentation. Their results showed that 6- to 8-month-old infants were able to identify a learned face after a
They could discriminate faces. This indicates that static poses may be advantageous for face learning. In these studies, 5.5-month-old infants were familiarized to the faces of one of three women performing one of three repetitive activities. Results indicated that infants could discriminate the actions but not the faces. Yet when infants were familiarized to static poses (Bahrick et al., 2002) or given a longer duration of familiarization time (Bahrick & Newell, 2008), they could discriminate faces. This indicates that static poses may be advantageous for three-dimensional face learning.

In this study, we presented face and non-face objects in static and in rotation and examined the rigid motion advantage in face learning. In order to compare the infants' recognition of faces and non-face objects, we used artificially produced three-dimensional objects.

We used a familiarization–novelty procedure to examine infants’ recognition ability for artificially three-dimensional objects learned in either rotating or static presentation. Infants were first familiarized with an object either in a rotating or a static presentation. After familiarization, infants were tested on their ability to recognize an object identity, that is, to discriminate a novel object from a learned object. These two objects were presented in static image in the test phase. In this paradigm, infants generally preferred to look at novel stimuli rather than familiar stimuli (novelty preference). Thus, a preference for the novel object at test indicated successful recognition of these objects.

**Methods**

**Participants**

Participants consisted of forty-eight 3- to 5-month-old infants and forty-eight 6- to 8-month-old infants. Half of the infants in both the younger and older groups viewed images of shoes (younger group: mean age of rotating presentation = 140.58 days, range = 110 to 157 days, 4 females, 8 males; mean age of static presentation = 135.83 days, range = 96 to 163 days; 5 females, 7 males; older group: mean age of rotating presentation = 205.25 days, range = 167 to 243 days, 6 females, 6 males; mean age of static presentation = 227.00 days, range = 201 to 250 days, 3 females, 9 males) and half viewed images of faces (younger group: mean age of rotating presentation = 137.75 days, range = 98 to 164 days, 6 females, 6 males; mean age of static presentation = 127.00 days, range = 98 to 155 days, 2 females, 10 males; older group: mean age of rotating presentation = 206.67 days, range = 174 to 246 days, 3 females, 9 males; mean age of static presentation = 231.08 days, range = 167 to 252 days, 3 females, 9 males). All were healthy Japanese infants who had a birth weight greater than 2,500 g. An additional fifty-nine infants were tested but were excluded from the analysis due to fussiness (11), a side bias greater than 95% (9), a preference for one of test stimuli (1), longer looking times in the last three familiarization trials than in the first three (36), or a total looking time in the two test trials of less than 6.0 s (2). The participants were recruited using advertisements in newspapers.

**Apparatus**

All stimuli were displayed on a Calix CDT2141A 21-in. CRT monitor (TOTOKU, Tokyo, Japan) controlled by a computer. The infant and the CRT monitor were located inside an enclosure that was made of iron poles and covered with cloth. Each infant sat on his or her parent’s lap in front of the CRT monitor. The infant’s viewing distance was approximately 40 cm. There were two loudspeakers, one on either side of the CRT monitor. There was a CCD camera just below the monitor screen.

**Experiment 1**

Regardless of changes in viewpoint, observers can recognize objects from almost any direction (Biederman & Gerhardstein, 1993, 1995). Our everyday experience of objects seen from various viewpoints may enhance the development of our object recognition ability across varying angles (Wang, Obama, Yamashita, Sugihara, & Tanaka, 2005). For infant face recognition, previous study has shown that 6- to 8-month-old infants can learn faces from various viewpoints (Nakato et al., 2010). Nakato et al. investigated the effect of presentation order in face learning and found that 6- to 8-month-old infants who were presented with sequentially rotated face images from profile to frontal views, but not in randomized presentation order, could identify the learned face.

This study suggests that infants around 6 to 8 months of age may have some ability for three-dimensional face representation. Since the face is a special object for infants, it is possible that infants’ object learning ability is limited to facial recognition. Here, we investigate differences in infants’ ability to learn three-dimensional recognition for faces and non-face objects. Beginning this study, we expected that learning of face and non-face would be enhanced by sequential rotating presentation.
Throughout the experiment, the infant’s behavior was videotaped through this camera. The experimenter could observe the infant’s behavior via a TV monitor connected to the CCD camera.

**Stimuli**

Objects were created using three-dimensional graphic software (Shade 9 Professional, e-frontier, Japan; Poser 7, Smith Micro software, California).

We used three different persons’ neutral expression faces and three different shoes. In order to prevent the possibility of infants responding to color, texture, or any other property of surface reflectance, we used a surface material that did not contain such cue information for both the faces and the non-face objects. Matte and unreflecting materials were selected to construct the object surfaces. The objects were illuminated by a light source located infinitely far from the object, in the direction of 45.0 degrees up to the object. All images were in grayscale. The maximum size of a viewed stimulus was 7.7 deg × 8.7 deg in visual angle, and the distance between the images was about 14.5 deg. The background was a homogeneous white field.

**Procedure**

We used a familiarization–novelty preference procedure to test the infants’ three-dimensional object recognition ability. The experiment consisted of three phases: the pre-familiarization test, the familiarization, and the post-familiarization test. First, infants participated in two 10.0-s pre-familiarization test trials. Then, they participated in six 15.0-s familiarization trials, which were immediately followed by two 10.0-s post-familiarization test trials. Prior to each trial, a cartoon accompanied by a short beeping sound was presented at the center of the monitor. The experimenter initiated each trial as soon as the infant was paying attention to the cartoon.

During the familiarization phase, infants learned one face or one shoe (Figure 1). The familiarization stimulus consisted of different viewpoint images of one face or one shoe either in rotating or static presentation. Half of the infants of both age groups were assigned randomly to the rotating presentation and the other half were assigned to the static presentation. In each presentation, half of the infants of both age groups were familiarized with one of the faces, and the other half were familiarized with one of the shoes. Stimuli in the rotating presentation were composed of 112 sequential images at 1.07-degree intervals.
of each object, which were shown repeatedly at a rate of 32.33 frames per second for each 15.0-s trial. These sequential images were created by rotating the vertical axis of the object from frontal view to ±60.0 deg. In addition, for the static stimuli, the six different viewpoint images at 24.0-degree intervals of each object were created in the same way as the rotating presentation. The six different viewpoint images were shown one by one sequentially from the left side to the right side for each 15.0-s trial (each static image was presented only one time in the familiarization phase). The familiarization stimulus appeared at the left and right sides of the CRT monitor.

Before the familiarization phase, we set a test phase to check infants’ spontaneous preference for a particular object. After the familiarization phase, we set another test phase to check infants’ novelty preference. In this paradigm, infants generally preferred to look at novel stimuli rather than familiar stimuli (novelty preference). Thus, a preference for the target (novel stimulus) indicated successful recognition of the learned stimuli during the learning phase. In the test phases, two objects were presented as static images side by side. One was a target (novel stimulus) and the other was a non-target (learned stimulus). The target was selected from the same category.

In cases in which shoes were selected as stimuli, the test stimuli were created by rotating the vertical axis of the shoe from a frontal view to +20.0 deg and additionally rotating the horizontal axis to 10.0 deg. In cases in which faces were selected as stimuli, the test stimuli were frontal views. The positions of the faces or shoes were reversed across the two trials for each infant. In addition, the positions of the target and non-target stimuli in the first trial were counterbalanced across infants.

One observer, who was unaware of the stimulus identity, measured the infants’ fixations to the left and right sides of the display based on video recordings. Only the infant’s looking behavior was visible in the video. Although the observer could not see the stimulus, she could notice the timing of the beginning and the end of each trial by means of the beep sound that was presented at those times.

To calculate the inter-observer agreement, a second observer’s measurement of infant’s looking time was obtained from 20.8% of the total data. Inter-observer agreement was \( r = 0.95 \) across this experiment.

## Results

### Familiarization trials

A preliminary analysis revealed no significant gender differences for participants, so data were collapsed across participant’s gender in subsequent analyses [with shoes, for 3- to 5-month-old infants, static presentation: \( F(4, 6) = 1.595, t(10) = -1.449 \); rotating presentation: \( F(3, 7) = 1.591, t(10) = -0.163 \); for 6- to 8-month-old infants, static presentation: \( F(2, 8) = 1.875, t(10) = 1.247 \); rotating presentation: \( F(5, 5) = 0.670, t(10) = -0.014 \), and with faces, for 3- to 5-month-old infants, static presentation: \( F(1, 9) = 1.973, t(10) = 0.779 \); rotating presentation: \( F(5, 5) = 0.658, t(10) = 0.080 \); for 6- to 8-month-old infants, static presentation: \( F(2, 8) = 1.526, t(10) = -0.921 \); rotating presentation: \( F(2, 8) = 0.577, t(10) = -1.772 \), all ns, t-test].

The individual looking times were summated across the first three and the last three trials (Table 1). The looking times of the first three decreased to the last in all presentations. For both faces and shoes, to examine the familiarization between the age groups and the presentations, a three-way ANOVA was performed for the looking times: (i) the trial (the first three, the last three) as a within-participants factor, (ii) the presentation for familiarization (the rotating presentation, the static presentation) as a between-participants factor, and (iii) the age of infants (3 to 5 months, 6 to 8 months) as a between-participants factor. The ANOVA revealed a significant decrease in looking times over trials for all presentations [with faces: \( F(1, 44) = 95.833, p < 0.0001 \); with shoes: \( F(1, 44) = 148.856, p < 0.0001 \)]. In addition, it indicated the significant main effect of the presentation for familiarization to face stimuli \( F(1, 44) = 7.671, p = 0.008 \) and not to shoe stimuli \( F(1, 44) = 2.743, p = 0.105 \).

The main effect of age and all interactions were not significant. For both presentations, the results showed that infants in each age group became familiarized with the

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Object</th>
<th>Presentation</th>
<th>3–5 months</th>
<th>6–8 months</th>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
<td></td>
<td>First three</td>
<td>Last three</td>
</tr>
<tr>
<td>1</td>
<td>Face</td>
<td>Static</td>
<td>39.2 (5.4)</td>
<td>33.1 (6.9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rotating</td>
<td>43.8 (1.9)</td>
<td>40.1 (4.6)</td>
</tr>
<tr>
<td></td>
<td>Shoe</td>
<td>Static</td>
<td>35.5 (7.6)</td>
<td>27.9 (6.6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rotating</td>
<td>35.9 (6.0)</td>
<td>30.2 (8.1)</td>
</tr>
<tr>
<td>2</td>
<td>Face</td>
<td>Rotating</td>
<td>42.3 (5.3)</td>
<td>38.5 (7.1)</td>
</tr>
<tr>
<td>3</td>
<td>Face</td>
<td>Rotating</td>
<td>39.5 (5.2)</td>
<td>34.3 (8.0)</td>
</tr>
</tbody>
</table>

Table 1. Looking time (seconds) and standard errors (in parentheses) during familiarization phases.
familiarization stimuli with no significant difference in decreased looking times between the age groups.

**Test trials**

A preliminary analysis revealed no significant gender differences for participants, so data were collapsed across participant’s gender in subsequent analyses [with shoes, for 3- to 5-month-old infants, static presentation: $F(4, 6) = 1.673, t(10) = -0.314$; rotating presentation: $F(3, 7) = 0.903, t(10) = 2.118$; for 6- to 8-month-old infants, static presentation: $F(2, 8) = 4.848, t(10) = 0.086$; rotating presentation: $F(5, 5) = 5.905, t(10) = -2.013$, and with faces, for 3- to 5-month-old infants, static presentation: $F(1, 9) = 0.031, t(10) = -0.586$; rotating presentation: $F(5, 5) = 1.611, t(10) = -0.169$; for 6- to 8-month-old infants, static presentation: $F(2, 8) = 0.292, t(10) = 1.458$; rotating presentation: $F(2, 8) = 0.573, t(10) = 0.522$, all ns, $t$-test].

The mean looking times during the pre-tests and the post-familiarization tests are shown in Table 2. In all test phases, all infants looked at the displays for more than 6.0 s. A novelty preference score was calculated for each infant in the pre-tests and the post-familiarization tests. This was done by dividing the infant’s looking time at the target by the total looking time. The ratios for the two test trials were averaged; Figure 2 shows the mean preference scores for all presentations. To determine whether infants preferred the target after they had been familiarized with the each condition, we conducted a two-tailed one-sample $t$-test (versus chance) on the preference score in the post-familiarization test. This analysis showed that for 6- to 8-month-old infants the post-familiarization preference score of face in only static presentation was significantly greater than the chance level of 50% [for 6- to 8-month-old infants, static presentation: $t(11) = 3.668, p = 0.0037$; rotating presentation: $t(11) = -0.289, p = 0.7781$; for 3- to 5-month-old infants, static presentation: $t(11) = 0.365, p = 0.7220$; rotating presentation: $t(11) = -0.391, p = 0.7036$], and the preference scores of shoe in both static and rotating presentations were not [for 6- to 8-month-old infants, static presentation: $t(11) = 1.511, p = 0.1590$; rotating presentation: $t(11) = 1.219, p = 0.2485$; for 3- to 5-month-old infants, static presentation: $t(11) = 0.411, p = 0.6892$; rotating presentation: $t(11) = -0.375, p = 0.7146$]. We conducted the same two-tailed one-sample $t$-tests

![Figure 2](http://jov.arvojournals.org/pdfaccess.ashx?url=/data/journals/jov/932793/)
Experiment 2

In Experiment 1, all infants failed to recognize the faces in rotating presentation, while 6- to 8-month-old infants could recognize the faces in static presentation. Previous adult face recognition study has shown that three-quarter views of faces promote better recognition for unfamiliar faces than full-face views (Bruce, Valentine, & Baddeley, 1987). In Experiment 1, we used the frontal view in the test phase, which should have made face recognition difficult for the infants. So, based on the adults’ data, we used three-quarter view faces in Experiment 2. We examined whether infants were able to recognize faces with three-quarter views in rotating presentation at test in Experiment 2.

Methods

Participants

Participants consisted of twelve 3- to 5-month-old infants (mean age = 130.25 days, range = 93 to 157 days, 3 females, 9 males) and twelve 6- to 8-month-old infants (mean age = 206.17 days, range = 172 to 254 days, 6 females, 6 males). The infants of both age groups viewed images of faces. All were healthy Japanese infants who had a birth weight greater than 2,500 g. An additional nine infants were tested but were excluded from the analysis due to fussiness (7), a side bias greater than 95% (1), or a preference for one of test stimuli (1). The participants were recruited using advertisements in newspapers.

Procedure and stimuli

The procedure and stimuli were the same as those used in the face condition of Experiment 1, with the following exception: The test stimuli were created by rotating the vertical axis of the face from frontal view to +20.0 deg and additionally rotating the horizontal axis to 10.0 deg.

Results

The total looking times from the first three and the last three trials are shown in Table 1. To compare differences in the familiarization between the age groups and the test stimuli, a three-way ANOVA was performed for the looking times: (i) the trial (the first three, the last three) as a within-participants factor, (ii) viewing angle of the test stimuli (the frontal views in Experiment 1, the three-quarter views) as a between-participants factor, and (iii) the age of infants (3 to 5 months, 6 to 8 months) as a between-participants factor. The ANOVA revealed a significant decrease in looking times over trials \(F(1, 44) = 88.695, p < 0.0001\) and the interaction of the trials \(x\) the age of infants \(F(1, 44) = 4.229, p = 0.046\). The main effect of the viewing angle on the test stimuli, age, and the other interactions was not significant. The results showed that infants became familiarized with the familiarization stimuli.

The mean looking times during the pre-tests and the post-familiarization tests are shown in Table 2. In all test trials, all infants looked at the displays for more than 6.0 s. We calculated a preference score for the target for each infant as in Experiment 1. The mean preference score in Experiment 2 is shown in Figure 3.

To determine whether infants had a spontaneous preference for either of the test displays, we conducted two-tailed one-sample \(t\)-tests (versus chance) on the preference score in the pre-test. The analysis showed that the preference scores for infants in both age groups did not differ from chance level [3- to 5-month-old: \(t(11) = -0.972, p = 0.3736\); 6- to 8-month-old: \(t(11) = -0.427, p = 0.6734\)] two-tailed: \(t\)-tests of repeated measures on Experiment 2.
These results suggest that infants showed no spontaneous preferences for faces. To determine whether infants preferred the target after they had been familiarized with the rotating presentation, we conducted two-tailed one-sample t-tests (versus chance) on the preference score in the post-familiarization test. The results revealed that the preference scores for infants in both age groups did not differ from chance level [3- to 5-month-old: \( t(11) = 0.471, p = 0.6471 \); 6- to 8-month-old: \( t(11) = -0.747, p = 0.4708 \)]. The results suggest that in rotating presentation infants could not recognize the familiarization faces even with the three-quarter views at test.

Experiment 3

In the static presentation of Experiment 1, 6- to 8-month-old infants successfully learned to recognize faces. In the rotating presentation, on the contrary, they failed to recognize faces presented both in frontal views (Experiment 1) and even in three-quarter views (Experiment 2) at test. The second possibility is that infants could not catch up with face processing in the rotating presentation. Previous infant vision studies investigated minimum speed thresholds of motion perception (Aslin & Shea, 1990; Bertenthal & Bradbury, 1992; Dannemiller & Freedland, 1989, 1993; Kaufmann, Stucki, & Kaufmann-Hayoz, 1985). Building on this data, in this experiment, we set slower speed rotation during the familiarization phase so that infants could easily perceive the faces. During the familiarization phase, the local speed of the nose, which was the fastest rotating point in a face, was about 2.74 deg/s. Therefore, we slowed down the frame rate frequency in the familiarization phases from 32.33 frames/s (Experiments 1 and 2) to 16.13 frames/s. We expected that a slower speed of rotation would enhance infants’ ability to recognize the faces.

Methods

Participants

Participants consisted of twelve 3- to 5-month-old infants (mean age = 137.92 days, range = 93 to 160 days, 7 females, 5 males) and twelve 6- to 8-month-old infants (mean age = 191.33 days, range = 168 to 252 days, 3 females, 9 males). The infants of both age groups viewed images of faces. All were healthy Japanese infants who had a birth weight greater than 2,500 g. An additional eleven infants were tested but were excluded from the analysis due to fussiness (1), a side bias greater than 95% (4), a preference for one of test stimuli (1), or longer looking times in the last three familiarization trials than in the first three (5). The participants were recruited using advertisements in newspapers.

Procedure and stimuli

The procedure and stimuli were the same as those used in the face condition of Experiment 1, with the following exception: In the familiarization trials, stimuli were composed of the 121 sequential images at 1.00-degree intervals of each face, which were shown repeatedly at a rate of 16.13 frames/s for each 15.0-s trial.

Results

The total looking times from the first three and the last three trials are shown in Table 1. To compare differences in the familiarization between the age groups and the test stimuli, a three-way ANOVA was performed for the looking times: (i) the trial (the first three, the last three) as a within-participants factor, (ii) the frequency of frame rate at the familiarization trials (32.33 frames/s in Experiment 1, 16.13 frames/s) as a between-participants factor, and (iii) the age of infants (3 to 5 months, 6 to 8 months) as a between-participants factor. The ANOVA revealed a significant decrease in looking times over trials \( F(1,44) = 76.233, p < 0.0001 \), the main effect of the age \( F(1,44) = 5.398, p = 0.025 \), and the frame rate frequency in the familiarization trials \( F(1,44) = 7.733, p = 0.008 \). All
interactions were not significant. The results showed that infants became familiarized with the familiarization stimuli. Furthermore, the 6- to 8-month-old infants looked at the display for a shorter time than the 3- to 5-month-old infants during the familiarization phase, and all infants looked at the display in Experiment 3 for a shorter time than in the rotating presentation of Experiment 1.

The mean looking times during the pre-tests and the post-familiarization tests are shown in Table 2. In all test trials, all infants looked at the displays for more than 6.0 s. We calculated a preference score for the target for each infant as in Experiment 1. The mean preference score in Experiment 3 is shown in Figure 4.

To determine whether infants had a spontaneous preference for either of the test displays, we conducted two-tailed one-sample t-tests (versus chance) on the preference score in the pre-test. The analysis showed that the preference scores for infants in both age groups did not differ from chance level [3- to 5-month-old: \( t(11) = -0.537, p = 0.6019 \); 6- to 8-month-old: \( t(11) = 0.338, p = 0.7417 \)]. These results suggest that infants showed no spontaneous preferences for faces.

To determine whether infants preferred the target after they had been familiarized with the low-speed rotating presentation, we conducted two-tailed one-sample t-tests (versus chance) on the preference score in the post-familiarization test. The results revealed that the preference scores for infants in both age groups did not differ from chance level [3- to 5-month-old: \( t(11) = -0.829, p = 0.4248 \); 6- to 8-month-old: \( t(11) = -0.651, p = 0.5287 \)]. The results suggest that infants could not recognize the familiarization face even when the familiarization stimuli were shown repeatedly in low-speed rotating presentation.

**Discussion**

Our results showed that face learning may be enhanced by viewing static images from different angles but not by viewing rotating images. On the contrary, object learning may be enhanced by viewing both static and rotating images. These results suggest that infants’ ability for face learning is different than their ability for non-face object learning in artificially produced three-dimensional object recognition.

As for infants’ object learning, our results differ from Kellman (1984; Kellman & Short, 1987). Kellman et al. found that 3- to 5-month-old infants could learn non-face objects when familiarized with either object or observer movement but not in static presentation. Our results showed that 6- to 8-month-old infants, but not 3- to 5-month-old infants, could learn non-face objects when familiarized with both static and rotating presentations. The difference in findings might be explained by the stimuli used. Kellman et al.’s experiments used bricks as objects—first, a single-volume brick triangle pole, then a single-volume brick L-shape. These objects could be easily discriminated, even by younger infants. On the contrary, the different shoes in one category in our experiment are not easily discriminated by infants.

For infant face learning, our results are consistent with Fagan (1972) and Nakato et al.’s (2010) findings that 6- to 8-month-old infants could generalize the learned face across views in static presentation. Although we predicted that the infants’ face learning would be enhanced by motion cue, our results did not show this effect. Rather, our results showed that infants could generalize a learned face across views only in static displays. Previous study has shown that infants’ face learning is enhanced by motion cue (Otsuka et al., 2009). Their study indicated that infants learned faces faster with facial expression motion than without motion. One possible difference between our study and that of Otsuka et al. concerns motion types. Otsuka et al.’s (2009) study used non-rigid motion in facial expression; we used rigid motion in rotating faces. It is possible that rigid motion is not useful information in face processing for infants. Our findings, consistent with that of Bahrick et al. (2002; Bahrick & Newell, 2008), suggest that static pose presentation has benefit for face recognition in infants’ everyday activities, which involve complex motion.

According to Bahrick & Newell’s (2008) study, when the familiarization period was extended from 160 s to 320 s, it was possible for infants to learn the faces. So, we reasoned that if 6- to 8-month-old infants had more...
familiarization time in our experiments, they might be able to learn faces in the rotating presentation. However, Bahrick & Newell (2008) used more complicated actions involving face and hand motions (e.g., brushing her teeth). In contrast to this, Nakato et al. (2010) used the same rotating motion stimuli as we did and had familiarization times almost similar to ours (Nakato et al.’s was 80 s and ours was 90 s). Therefore, our stimulus presentation time seems to be sufficient. Furthermore, we compared the familiarization pattern of 6- to 8-month-old infants between the static and rotating presentations in our experiment (see Table 1). We checked (1) the total looking times for each presentation and (2) the decrease in looking times, which was determined by subtracting the last three familiarization trials from the first three in each presentation. We found no difference in results between the static and rotating presentations [(1) $F(1, 22) = 0.581, p = 0.454$ and (2) $F(1, 22) = 2.188, p = 0.1532$, the ANOVA with presentation condition (static vs. rotating)]. Taking these results together, we have concluded that the differences in our results between static and rotating presentations were due to the presentation conditions, not the familiarization times.

One speculation should be that facial expression conveys emotion. It is known that a specific brain region is involved in processing the visual information for emotional expression (Morris et al., 1998). In Otsuka et al.’s (2009) study, it might have been easier for infants to learn faces because their stimuli contained emotion.

Moreover, we compared the infants’ learning between faces and non-face objects. Previous studies have shown that visual processing is different for faces and non-face objects (e.g., de Haan & Nelson, 1999). de Haan et al. recorded the brain activity of 6-month-old infants while they were looking at static images of both objects and faces. They found that the P400 (a face-sensitive ERP component in the case of the infants) was of a shorter latency for faces than for non-face objects independent of familiarity, possibly reflecting faster initial processing of faces than of objects. Furthermore, Otsuka et al. (2007) showed different brain activity for face and non-face objects in 5- to 8-month-olds. In their study using near infrared spectroscopy (NIRS), they measured changes in cerebral oxygenation in ten 5- to 8-month-olds’ left and right lateral areas while the infants were looking at faces and non-face objects. They found that the concentration of oxy-Hb and total-Hb significantly increased in the right lateral area during the presentation of faces compared to the presentation of objects (vegetables). Our research provides further evidence that infants process faces differently from non-face objects.

In this study, infants could learn non-face objects in both static and rotating presentations. In contrast, infants could learn faces only in static but not rotating presentation. These results suggest that although the face has three-dimensional aspects, face learning does not follow the law of three-dimensional object learning; usually, object learning is facilitated by rotating. In addition, in face learning, we did not find the three-quarter views advantageous at test. At test, we used the frontal view in Experiment 1 and the three-quarter view in Experiment 2. In both experiments, we did not find any learning in the rotating presentation condition. We found the same negative results even in different view presentations at test, as did the adult study (Liu & Chaudhuri, 2002).

Bulf and Turati (2009), Fagan (1972), and Nakato et al. (2010) indicated that even newborns might generalize a three-dimensional face. However, these researchers used three-dimensional faces with textural information. Additionally, they did not compare this generalization between faces and non-face objects. So, the three-dimensional object representation of faces and non-face objects in infants is not clarified. Our research directly compared the generalization of three-dimensional objects between face and non-face objects. In addition, to investigate simply three-dimensional object recognition, we created three-dimensional face and non-face objects that did not contain texture and a fixed light source. Thus, it appears that processing facial information of three-dimensional objects without texture information is difficult for infants.

For face learning in Experiments 1 and 2, it was simply possible that infants could not process the complicated face with a fast rotation. However, the results of Experiment 3 belie this explanation since in Experiment 3 we set the rotation speed to the minimum threshold for infant motion processing established by previous studies (Aslin & Shea, 1990; Bertenthal & Bradbury, 1992; Dannemiller & Freedland, 1989, 1993; Kaufmann et al., 1985). Moreover, we set this speed at the point of the nose, yet infants could not generalize the rotating face even in Experiment 3.

One possibility is that the difference of physical similarity among each category (face and non-face objects) might cause a difference in infants’ ability to learn faces and non-face objects. However, this possibility can also be eliminated. With the all stimuli of static presentation, we calculated the similarity between the two images as the Euclidean distance between coefficients of their wavelet transformations. When the distances were compared between two images picked up from one face or one shoe and two images picked up from a different shoe or face within the same category (face or non-face objects), there was no significant difference for these distances [faces, pairs within 0.74, pairs across 0.78, $p = 0.197$, $t$-test; shoes, pairs within 0.59, pairs across 0.69, $p = 0.069$, $t$-test]. The same results were obtained when the similarity between the two images was calculated as the Euclidean distance between the luminosity values in individual pixels (Op de Beeck, Wagemans, & Vogels, 2001). In addition, we calculated overall luminance and contrast for all faces and all non-face objects. We have conducted the ANOVA on within faces and within non-face objects. The ANOVA did not show any differences of the overall luminance and contrast within the same category [within faces, overall luminance: $F(2, 21) = 0.230, p = 0.7962$; overall contrast:
three-dimensional object recognition. due to differences of physical properties between faces and non-face objects. These suggest that the face is a special object for infants even in artificially produced non-face objects. These suggest that the face is a special object for infants even in artificially produced three-dimensional object recognition.

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