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Recognition of Moving and Static Faces by Young Infants

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This study compared 3- to 4-month-olds' recognition of previously unfamiliar faces learned in a moving or a static condition. Infants in the moving condition showed successful recognition with only 30 s familiarization, even when different images of a face were used in the familiarization and test phase (Experiment 1). In contrast, infants in the static condition showed successful recognition only when the familiarization duration was lengthened to 90 s and when the same image was used between the familiarization and test phase (Experiments 2 and 3). Furthermore, presentation of multiple static images of a face did not yield the same level of performance as the moving condition (Experiment 4). These results suggest that facial motion promotes young infants' recognition of unfamiliar faces.

Previous developmental studies show consistently that motion information plays an important role in infant visual perception (e.g., Kellman, 1984; Kellman & Spelke, 1983; Otsuka & Yamaguchi, 2003; Owsley, 1983; Valenza & Bulf, 2007). Studies of the importance of motion for infant perceptual development have been influenced strongly by J. J. Gibson's proposal that temporal transformations of the optic array can provide far richer information about the visual world than the projection of a single static image onto the retina (J. J. Gibson, 1966; for a review, see Dodwell, Humphrey, & Muir, 1987). This observation is at the core of proposals in the developmental literature that motion may play a key role in young infants' ability to detect invariant patterns of stimulation through temporal changes (E. J. Gibson & Pick, 2000).

In fact, motion-based information is one of the earliest cues young infants can exploit for depth perception (Yonas & Owsley, 1987). Arterberry and Yonas (1988, 2000) demonstrated that even 2- and 4-month-olds can detect and discriminate three-dimensional shapes depicted by kinetic random dot displays, in which object shape is specified solely by the motion pattern of the moving dots. Moreover, there is evidence indicating that motion information promotes 4-month-old infants' perception of three-dimensional objects (Kellman, 1984; Owsley, 1983). Studies on the perception of partially occluded objects and illusory contours likewise attest to the importance of motion for infant perception. Kellman and Spelke (1983), for example, compared infants' perception of partially occluded static and moving objects and found that 4-month-olds perceive the continuity of a partially occluded object only when the object is in motion. Similarly, Otsuka and Yamaguchi (2003) demonstrated that 3- to 6-month-olds perceived illusory contours only with a moving display, whereas 7- to 8-month-olds perceived illusory contours from both moving and static displays. Valenza and Bulf (2007) extended the results of Otsuka and Yamaguchi (2003) to show that newborn infants can perceive illusory contours only from a moving display.

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Among the many objects infants perceive, faces are unique in that infants encounter faces nearly exclusively in motion. It seems likely, therefore, that the facial motion seen in everyday life might promote infants' ability to recognize faces. It has been noted frequently that faces are a special class of objects that can provide social communication signals from early in life. Some of the most important facial movements are seen in the nonrigid motions that convey facial expressions. There is evidence suggesting that faces are processed differently from nonface objects in infants as well as in adults (e.g., de Haan & Nelson, 1999; Otsuka et al., 2007). The social communication function of faces suggests that motion may be an integral component of the infants' experience with faces and further suggests that it may be interesting to examine whether infants recognize faces better in moving than static displays.

Although face recognition studies have traditionally relied on static images of faces as stimuli, there is growing interest in the role of motion in facial recognition. In a recent review of the adult face recognition literature, O'Toole, Roark, and Abdi (2002) proposed two nonmutually exclusive hypotheses about the possible benefits of motion for face recognition. The *supplemental information hypothesis* posits that motion information can contribute to face recognition by providing supplemental identity-specific information about a face in the form of *dynamic identity signatures*. Dynamic identity signatures are characteristic facial expressions, movements, or facial gestures (e.g., a particular way of smiling, nodding, or gesturing). O'Toole et al. (2002) hypothesized that the motion information in dynamic identity signatures should be more beneficial for recognizing familiar faces than for recognizing unfamiliar faces. This is because multiple encounters with a person may be required to learn a person's characteristic facial gestures. The use of dynamic identity signatures for recognition, therefore, draws on past memory for movements that are associated with an individual.

A second quite different way that motion might benefit face recognition is summarized in the *representation enhancement hypothesis* (O'Toole et al., 2002). This hypothesis posits that motion information can contribute to face recognition by facilitating the perception of the three-dimensional shape of a face. Representation enhancement is based on the well-known capacity of the perceptual system to use motion information to derive three-dimensional shape representations. Classic kinetic depth effects (Wallach & O'Connell, 1953) and biological motion phenomena (Johansson, 1973) are examples of the capacity of motion to enhance the quality of three-dimensional shape perception. Kinetic depth effects and biological motion are pure structure-from-motion effects because they illustrate cases where three-dimensional structure is perceived in ''random'' dot-patterns *only* when the dots are in motion. In more natural viewing conditions, structure-from-motion processes operate on representations that also contain pictorial information. The potential benefits of representation enhancement processes for face recognition are perceptual and thereby not dependent on prior experience with a particular face. Perceptual enhancement should enhance the process of learning an unfamiliar face.

Psychophysical studies with adults' face recognition (for review, see O'Toole et al., 2002; Roark, Barrett, Spence, Abdi, & O'Toole, 2003) have found support for the supplemental information hypothesis but not for the representation enhancement hypothesis. Specifically, previous studies have shown consistently that identity-specific facial motion can be used for face recognition (e.g., Hill & Johnston, 2001; Knappmeyer, Thornton, & Bulthoff, 2003) and that motion information facilitates the recognition of familiar faces (Bruce & Valentine, 1988; Lander & Bruce, 2000; Lander, Bruce, & Hill, 2001; Lander, Christie, & Bruce, 1999). To date, however, there is no conclusive evidence for the representation enhancement hypothesis. Although some studies have found better recognition of unfamiliar faces using dynamic rather than static stimuli (Lander & Bruce, 2003), other studies have not (Christie & Bruce, 1998).

One possible reason for the lack of conclusive evidence in support of the representation enhancement hypothesis is that adults' ability to perceive and represent faces is at ceiling. Thus, it may be difficult to assess the perceptual effects of facial motion on the recognition of unfamiliar faces. For adults, who have mature perceptual and cognitive abilities, static images of a face provide more than enough pictorial information to create a high-quality representation of the face. If this is the case, the effect of seeing a face in motion might be easier to measure in young infants whose perceptual and cognitive systems are in the course of development.

Previous developmental studies on infant's face recognition, however, offer mixed support for the claim that motion is beneficial. These studies can be grouped into three categories: (a) tests of infants' ability to discriminate face and nonface stimuli, (b) tests of infants' abilities to discriminate faces by expression (and pose), and (c) tests of infants' ability to differentiate faces by identity.

In the first category, several studies suggest that motion information enhances infants' ability to discriminate face from nonface stimuli. For example, Stucki, Kaufmann-Hayoz, and Kaufmann (1987) examined whether 3-month-old infants could discriminate between a woman's face and a single object using a motion-based cue to the structure of the object and face. When the static features of a face and an object were obscured by embedding them in a textured background, infants were able to discriminate between the face and the object when both were viewed upright. In addition, Johnson, Dziurawic, Bartrip, and Morton (1992) measured infants' spontaneous preferences for schematic versus scrambled faces with the same features. They found that 5-month-olds preferred the schematic face only when the internal features were moving.

In the second category of studies, the question of whether motion facilitates infants' abilities to discriminate facial expressions has been investigated in several experiments. Wilcox and Clayton (1968) measured 5-month-olds' preferences for three categories of facial expression (smiling, frowning, and neutral) in ''moving'' and ''static'' face presentations. They found differences in looking times for facial expressions only in the static face condition. Biringen (1987) also found no beneficial effect of motion information on infants' preference for facial expressions. She measured 3-month-olds' preferences for facial expressions in a static condition, an internal feature motion condition, and in a head motion condition. Infants discriminated facial expressions in the static condition and in the internal feature motion condition but not in the head motion condition.

More evidence on this question comes from Nelson and Horowitz (1983) who examined whether 5-month-olds can discriminate between expressions and poses in a static and moving condition. They used two holographic stereogram stimuli depicting the same woman's face varying in expression and pose. Infants who viewed different faces in the habituation and test phase showed dishabituation in both the moving and static conditions. Infants who viewed the same stimuli across the two phases, however, showed the same amount of dishabituation as the infants who saw different faces. Thus, it is difficult to conclude that the 5-month-olds in this study discriminated between expressions and poses either in the moving or static conditions. Similar to the findings of Biringen (1987) and Wilcox and Clayton (1968), the finding of Nelson and Horowitz is unclear about whether dynamic stimuli benefit infants' discrimination of facial expressions.

Dynamic facial expressions have also been used as part of intermodal stimuli to test infants' ability to match facial expressions across different modalities and to discriminate facial expressions (for a review, see Walker-Andrews, 1997). Researchers investigating these problems have emphasized the importance of using naturalistic, dynamic, and multimodal presentations as the optimal stimulus for young infants (e.g., Caron, Caron, & MacLean, 1988; Walker-Andrews, 1997). For example, Caron et al. (1988) found that 5-month-olds discriminated between happy and sad expressions, regardless of whether they were accompanied by a concordant vocal expression. In contrast, 7-month-olds, but not 5-month-olds, successfully discriminated between happy and angry expressions only when both facial and vocal information were available. Consistent with these findings, Walker (1982) found that 5- and 7-month-olds discriminated between the dynamic facial expressions (happy and angry) by showing preference for the facial expression that was affectively matched to the vocal expression. This preference was found even when the facial and vocal stimuli were presented asynchronously, and even when the lip movements were occluded and invisible (Walker-Andrews, 1986). However, the preference disappeared when the facial images were inverted (Walker, 1982). In summary, when dynamic multimodal stimuli are employed, there is evidence that infants can discriminate facial expressions in dynamic stimuli.

A more direct look at infants' ability to utilize facial motion to discriminate facial expression comes from a study using point-light stimuli (e.g., Bassili, 1979), in which facial feature information cannot be obtained from the image. Soken and Pick (1992) showed that 7-month-old infants looked longer at facial expressions (happy vs. angry) that were affectively concordant with the vocal expression in both normally illuminated faces and point-light faces. They conclude that infants can discriminate between facial expressions based solely on facial motion information.

The third category of studies concerns the ability of infants to discriminate facial identity in dynamic stimuli. This question has been examined in: (a) studies of intermodal perception of moving faces accompanied by voice, (b) self-recognition studies, and (c) direct tests of identity discrimination from moving stimuli. The intermodal perception studies demonstrate that infants can match between a face and voice according to gender (Patterson & Werker, 2002; Walker-Andrews, Bahrick, Raglioni, & Diaz, 1991), age (Bahrick, Netto, & Hernandez-Reif, 1998), and the individual identity of a familiar person (Spelke & Owsley, 1979). Infants can also learn arbitrary relation between faces and voices (Bahrick, Hernandez-Reif, & Flom, 2005; Brookes et al., 2001).

The self-recognition studies suggest that visual self-recognition is somewhat more robust and consistent when it is tested with dynamic rather than static stimuli Bahrick, Moss, and Fadil (1996), for example, found that 5- and 8-month-olds preferred an age-matched peer over the ''self'' when presented in a moving display condition. However, only 8-month-olds showed this preference in the static condition. In a related study, Legerstee, Anderson, and Schaffer (1998) examined infants' preferences for self versus peer by using both moving and static images. Consistent with Bahrick et al., they found that both 5- and 8-month-olds preferred the peer over the self in the moving condition. In the static condition, 8-month-olds showed the same peer preference, whereas 5-month-olds preferred the self over the peer.

Using a direct test of identity discrimination, Bahrick, Gogate, and Ruiz (2002) reported that highly salient motions produced by everyday activities may not always be beneficial for face recognition but may actually distract infants from processing a face. They compared recognition memory for faces and actions, using movies in which a female model performed a repetitive action involving face and hand motions (e.g., brushing her teeth). After a 160-s familiarization period, 5-month-olds showed recognition memory for the action, but not for the face. Face recognition was found when infants were familiarized and tested using static images. In a follow-up study, Bahrick and Newell (in press) found that 5-month-olds could learn to recognize faces from the same movie when the familiarization duration was extended to 320 s or when they were habituated to a movie depicting the same person performing multiple actions. The study showed that the ''distracting'' effect of motion was minimized if infants were habituated to a variety of actions performed by the same person, thereby making the actions less salient and promoting attention to the face.

The most direct test of infants' ability to discriminate identity on the basis of facial motion along comes from a recent study by Spencer, O'Brien, Johnston, and Hill (2006). They tested infants' ability to discriminate individuals using dynamic identity signatures as the facial motion signal (O'Toole et al., 2002; Roark et al., 2003). Spencer et al. used a stimulus generation paradigm similar to the one used previously by Hill and Johnston (2001) to show that adults can use dynamic identity signatures for face recognition. Using a facial feature tracking system, Spencer et al. recorded motion patterns from the faces of actors who were telling a joke. Next, they projected the recorded motion patterns from the model onto an average face computed from a large number of laser scans (Vetter & Troje, 1997). Infants aged 4 to 8 months of age were habituated to the average face with the motion pattern of a particular actor telling a joke. After habituation, infants viewed the average face with a motion pattern from the same actor and a new actor, side by side. Although both faces were presented telling a new joke, infants showed a significant preference for the face displaying a motion pattern from the new actor. This indicates that infants are sensitive to dynamic identity signature information when it is useful for discriminating individuals.

Combined, previous findings suggest that infants are skilled at abstracting information about facial expressions and facial identity in moving displays. In the light of the two hypotheses about the effect of facial motion proposed for adult face recognition (O'Toole et al., 2002), the study by Spencer et al. (2006) clearly demonstrates that infants can use dynamic facial identity signature motions to differentiate individuals. This is consistent with the findings from the adult literature (Hill & Johnston, 2001; Knappmeyer et al., 2003; Lander & Bruce, 2000; Lander et al., 1999, Lander et al., 2001), and supports the supplemental information hypothesis in the case of infants as well as in adults. What is still unknown, however, is whether facial motion has a beneficial effect on face recognition through facilitating the perception of facial structure, similar to the role of motion for the perception of object shape and biological form. In other words, can motion improve infant face recognition via representation enhancement processes?

The aim of this study was to test whether facial motion can help infants learn new faces. As noted previously, there is evidence indicating that young infants utilize motion information to perceive invariant three-dimensional shape (Arterberry & Yonas, 1988, 2000; Kellman, 1984; Owsley, 1983) and that motion can facilitate the perception of an object (Kellman & Spelke, 1983; Otsuka & Yamaguchi, 2003; Valenza & Bulf, 2007). Further, a recent study looking at infant scanning behavior suggests that a naturalistic facial movie attracts infants' gaze to the internal features of faces at an earlier age than suggested by other studies using static facial images (Hunnius & Geuze, 2004). Based on these previous findings, we hypothesized a facilitative effect of motion for infant face recognition. Analogous to object perception findings, we expected motion to affect face recognition through facilitating the extraction of structure information and/or attract attention to the internal features. To test this possibility, we compared infants' recognition of previously unfamiliar faces learned in moving and static presentations.

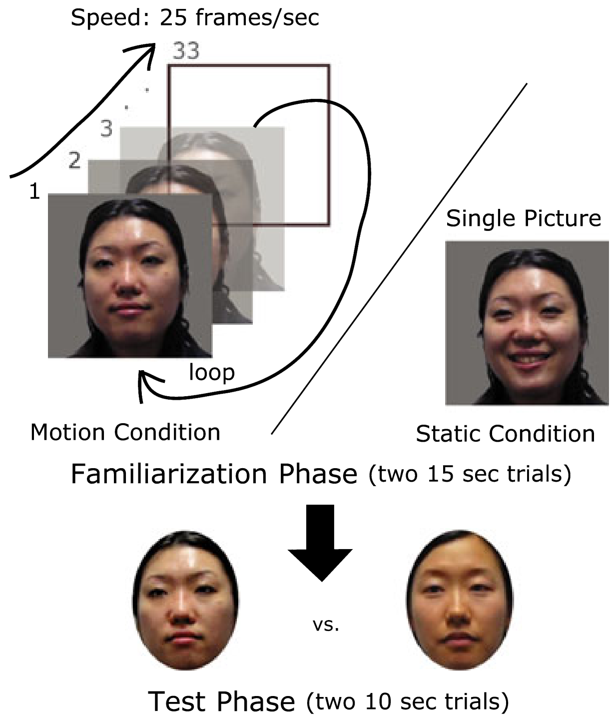

Figure 1. Illustration of familiarization and test stimuli used in the moving and static condition in Experiment 1.

Experiment 1

We used a familiarization–novelty procedure to examine infants' recognition memory for faces learned in either a moving or static familiarization condition. Infants were first familiarized with a smiling female face either in the moving or static condition (Figure 1, top). The familiarization phase was fixed at a relatively short duration (30 s). We assumed that a longer familiarization time might result in different looking times between the moving and static conditions, because infants generally look longer at moving than the static stimuli (Slater, 1995). Thus, we employed this short familiarization duration to avoid differential looking times during familiarization between the moving and static conditions. After familiarization, infants were tested on their ability to recognize a facial identity across varying facial images, using a pair of novel and familiar female faces (Figure 1, bottom). Both novel and familiar faces in the test phase had static, neutral expressions. In this paradigm, infants generally prefer to look at novel stimuli rather than familiar stimuli (novelty preference). Thus, a preference for the novel face indicates successful recognition of the face learned during the familiarization phase. Because we used varying facial images between the familiarization and test phase, successful performance on the novelty preference test in this procedure requires infants not only to discriminate between the faces but also to generalize their memory for the familiarized face across images. This procedure has the advantage of ensuring that we are measuring face recognition, rather than picture-based image matching (Kelly et al., 2007).

Method

Participants. Twenty-four 3- to 4-month-old infants (mean age of moving condition = 102.67 days, range = 81 to 120 days, mean age of static condition = 102.66 days, range = 83 to 119 days; 10 females, 14 males) participated in this experiment. All were healthy Japanese infants who had a birth weight greater than 2,500 g.

An additional 17 infants were tested, but were excluded from the analysis due to fussiness (7), a side bias greater than 90% (9), or looking times in the familiarization trials that were less than 20 s (1).

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, which 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. Throughout the experiment, the infant's behavior was videotaped through this camera. The experimenter could observe the infant behavior via a TV monitor connected to the CCD camera.

Stimuli. All stimuli were produced from two video clips, which were taken from a database of moving and static faces collected at the Vision Lab at The University of Texas at Dallas (O'Toole et al., 2005). We selected two ''dynamic facial expression'' clips of two different Asian females from the database. These recorded spontaneous dynamic smiling expressions while the model watched a video.

The familiarization stimulus consisted of a smiling female face seen either in the moving or static condition. The familiarization stimuli were produced by extracting a period consisting of 33 frames from each of the two video clips, while the face showed a smiling expression. Stimuli in the moving condition (Figures 2a and 2b) were composed of the 33 frames extracted from the video clips, which were shown repeatedly at a rate of 25 frames per second for each 15-s trial. Static stimuli were composed of the last frame of the moving stimulus (shown in Figures 2c and 2d). Familiarization stimuli subtended about 22° of visual angle (VA) horizontally and vertically. These stimuli were presented at the center of the CRT monitor.

In all conditions, the test stimuli consisted of two static female faces with a neutral expression (Figures 2e and 2f) shown side by side. The test stimuli were produced by capturing an image in each of the two video clips from the period preceding those used for the familiarization stimuli. To eliminate the possibility that infants could discriminate the two faces based on the external features, we excluded hair from the test stimuli so that only the internal features were visible. Each facial image subtended about $16 \times 19°$ of VA, and the distance between the images was about 17.5° of VA.

Procedure. The experiment consisted of two phases—a familiarization session and a postfamiliarization test. First, infants participated in two 15-s familiarization trials, which were followed immediately by two 10-s 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 paid attention to the cartoon.

In the familiarization trials, infants viewed a smiling female face either in the moving or static condition. Half of the infants were assigned randomly to the moving condition and the other half were assigned to the static condition. In each condition, half of the infants were familiarized with one of the two female faces, and the other half of the infants were familiarized with the other face. In this way, the familiar versus novel status of the two test faces was counterbalanced across infants.

The familiarization stimulus appeared at the center of the CRT monitor. In the test trials, one novel female face and one familiar female face were shown in side by side. The positions of the faces were reversed across the two trials for each infant. In addition, the positions of the faces in the first trial were counterbalanced across infants.

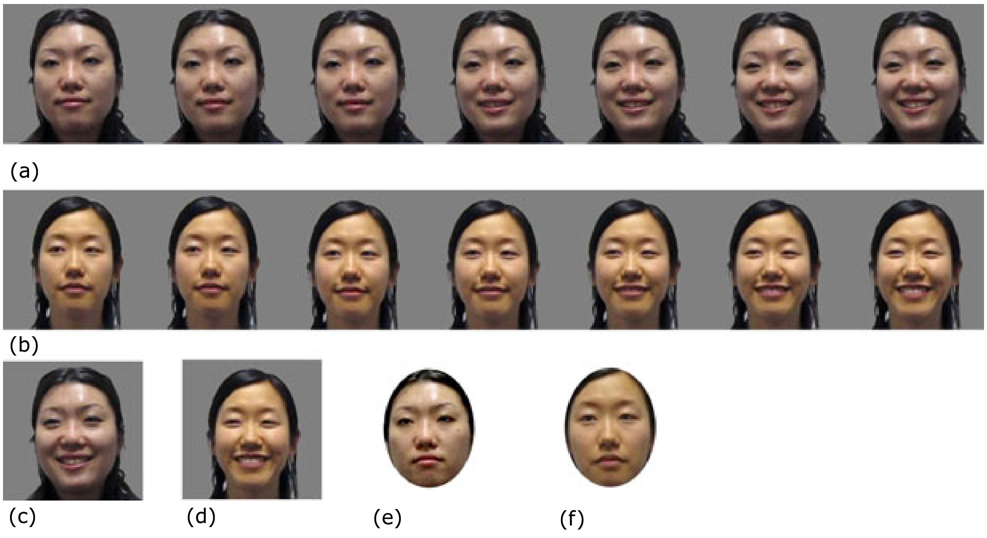

Figure 2. Illustration of the stimuli used in the experiment. Images extracted from the familiarization stimuli in the moving condition (a and b), static condition (c and d), and test stimuli (e and f).

One observer, unaware of the stimulus identity, measured infants' looking time for each stimulus based on the video recordings. Only the infant's looking behavior was visible in the video. To compute the interobserver agreement, a second observer's measurement of infant's looking time was obtained from about 40% of the data set. Interobserver agreement was $r = .99$ throughout experiments.

Results and Discussion

Familiarization trials. The mean total looking time from the two-familiarization trials in the moving and static conditions are shown in Table 1. A two-tailed *t*-test revealed no significant difference between the total looking time during familiarization between the moving and static conditions, $t(22) = 0.56$, $p > .1$. The results show that the exposure duration to the face during the familiarization phase was the same across two conditions.

Test trials. The mean total looking times in the test trials was 18.27 s in the moving condition and 18.43 s in the static condition. We calculated a preference score for each infant. This was carried out by dividing the infant's looking time to the novel face during two test trials by the total looking time over the two test trials, and then multiplying this ratio by 100. The mean preference scores in the moving and static conditions appear in Table 1. To determine if infants recognized the faces, we conducted two-tailed one-sample *t* test (vs. chance level 50%) on the preference scores. This analysis revealed that infants showed a significant preference for the novel face in the moving condition, $t(11) = 2.88$, $p = .015$, but not in the static condition, $t(11) = -0.7$, $p > .1$. Further, a two-tailed *t* test revealed that the preference score was significantly greater in the moving condition than in the static condition, $t(22) = 2.79$, $p = .011$.

Table 1
Mean Total Looking Times in Seconds During the Familiarization Trials and Mean Novelty Preference Scores in Percentages During the Test Trials

Experiment	Familiarization condition	Total looking times (*SD*)	Novelty preference scores (*SD*)
1	Moving	27.80 (1.81)	66.42 (19.72)
	Static	27.42 (1.53)	47.34 (13.16)
2	Static	28.40 (0.81)	53.36 (19.62)
3	Static	80.89 (12.07)	62.29 (2.85)
4	Stop motion	28.00 (1.69)	51.37 (14.43)

These results show that infants could recognize the familiarized face when they learned the face from the moving condition, but not from the static condition, thereby suggesting that motion information facilitates infants' learning of unfamiliar faces.

We did not find recognition of the faces familiarized in the static condition. This stands in contrast to previous studies that have demonstrated that even newborns can recognize faces learned from static images (e.g., Turati, Bulf, & Simion, 2008; Turati, Macchi Cassia, Simion, & Leo, 2006). The difference in findings might be explained by the following two important methodological differences between the studies.

First, the familiarization period was set to a relatively short duration (total 30 s) in this study. Second, we used different images of a face between familiarization and test, requiring that the infant generalize recognition of the face between these images. This latter defines a strict criterion for face recognition that eliminates alternative explanations of recognition based on image features. Combined, these conditions should have made the face recognition task more difficult for infants than the conditions used in the previous studies.

In addition, the use of different images at familiarization and test might have inhibited infants' ability to discriminate faces in the static condition due to the externality effect. The externality effect refers to the inability of very young infants to process static features surrounded by external contours. This effect is typically found in infants younger than 2 months of age (Bushnell, 1979; Milewski, 1976). Because external facial features were masked and unavailable during the test phase, the failure of recognition in the static condition might be related to the externality effect. Although recent studies showed that even newborn infants can detect the internal features of a face (e.g., Slater et al., 2000), an extensive investigation of this problem revealed that neonates show difficulty in recognizing faces based solely on the internal features when the task involves a transition of the image (with or without external features) between the habituation and test phase (Turati et al., 2006). Given that a similar transition of the image was present in Experiment 1, this might have caused difficulty for the 3-month-old infants we tested.

Experiment 2 was designed to determine if infants could recognize faces learned in the static condition when the task was made easier by providing the same information in both the familiarization and test phases, including the hair. In Experiment 2, the same image containing an external feature (the hairline) was used in both the familiarization and the test phase.

Experiment 2

We examined whether infants could recognize faces familiarized in the static condition when the same image was used for the familiarization and test phases. Infants were familiarized with a face in the same way as in the static condition of Experiment 1. Then, they were tested using the same image (face image including hairline) shown during the familiarization phase (see Figure 3).

Method

Participants. Twelve 3- to 4-month-old infants (mean age = 117.5 days, range = 89 to 133 days; 5 females, 7 males) participated in this experiment. All were healthy Japanese infants who had a birth weight greater than 2,500 g.

An additional three infants were tested but were excluded from the analysis due to fussiness (1) or to a side bias greater than 90% (2).

Procedure and stimuli. The procedure and stimuli were the same as those used in the static condition of Experiment 1, with the following exceptions. The image used for the familiarization phase (Figures 2c and 2d) was also used in the test phase. All infants were familiarized with a face in the static condition (see Figure 3).

Results and Discussion

The mean total looking time from the two-familiarization trials is shown in Table 1. The mean total looking time in the test trials was 18.46 s. We calculated a preference score for each infant as in Experiment 1. The mean preference score in Experiment 2 is shown in Table 1. A two-tailed one-sample t test (vs. chance level 50%) on the preference scores revealed that the preference scores were not significantly different from the chance level of 50%, $t(11) = 0.59$, $p > .1$. The result suggests that infants could not recognize the familiarization face even when the same image was used between the familiarization and test phase, with the external features available in both phases.

Experiment 3

In this experiment, we examined whether infants are able to recognize faces familiarized in the static condition when the duration of familiarization is extended. Specifically, we extended the duration of the familiarization phase from two 15-s trials (Experiments 1 and 2) to six 15-s trials. The duration was determined by our preliminary experiments and is compatible with that used in several other studies examining young infants' perception (e.g., Otsuka, Konishi, Kanazawa, & Yamaguchi, 2008; Quinn & Eimas, 1996; Quinn & Schyns, 2003; Spencer et al., 2006).

Method

Participants. Twelve 3- to 4-month-old infants (mean age = 105.83 days, range = 83 to 128 days; 8 females, 4 males) participated in this experiment. All were healthy Japanese infants who had a birth weight greater than 2,500 g.

An additional two infants were tested but were excluded from the analysis due to fussiness (1) or to a side bias greater than 90% (1).

Procedure and stimuli. The procedure and stimuli were the same as those in Experiment 2 except that the familiarization duration was extended to six 15-s trials (see Figure 3).

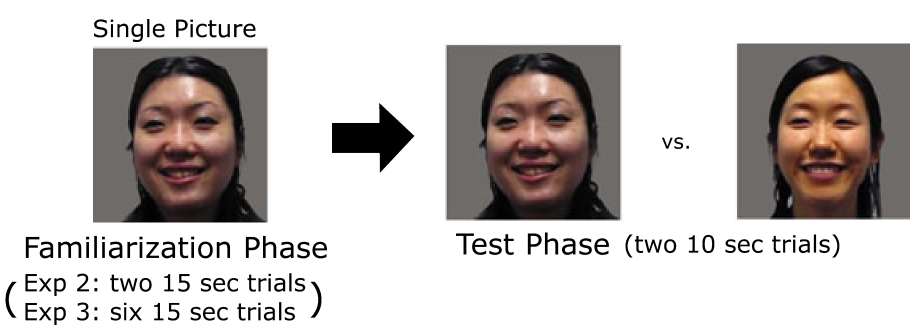

Figure 3. Illustration of familiarization and test stimuli used in Experiments 2 and 3.

Results and Discussion

The mean total looking times from the two-familiarization trials appear in Table 1. The mean total looking time in the test trials was 19.05 s. We calculated a preference score for each infant as described in Experiments 1 and 2. The mean preference score in Experiment 3 is shown in Table 1. A two-tailed one-sample *t* test (vs. chance level 50%) on the preference scores revealed that the preference scores were significantly above the chance level of 50%, $t(11) = 2.98$, $p = .013$. The results suggest that infants recognized the familiarization face in the static condition when the familiarization duration was extended to 90 s. The successful recognition of faces in the static condition is therefore compatible with the previous studies showing young infants' recognition of previously unfamiliar faces (e.g., Turati, Sangrigoli, Ruel, & de Schonen, 2004). In addition, a comparison of the results from Experiments 2 and 3 suggests that infants show better recognition and discrimination of faces following longer familiarization duration. This finding is consistent with other studies finding that face recognition in infants improves with longer familiarization durations (Bahrick & Newell, in press; Bahrick et al., 2002).

Experiment 4

The results from Experiments 1–3 showed that 3- to 4-month-olds were able to learn a face with only 30 s of familiarization in the moving condition but needed 90 s of familiarization to learn a face in the static condition. These results indicate that motion information promotes infants' learning of faces. However, the familiarization displays in the moving condition differed from those in the static condition, not only in the presence of motion information but also in terms of the static information. Whereas infants in the moving condition viewed multiple static pictures (33 frames) of a face during the familiarization trials, infants in the static condition viewed only a single picture of the face (the last of the 33 frames). Thus, seeing the same face in the multiple static pictures might account for the better performance in the moving condition in Experiment 1.

To control for this possibility, we created new familiarization stimuli that consisted of the same 33 frames of static pictures used in the moving condition but presented then in a ''stop motion sequence'' (stop motion condition). In this condition, the image sequence consisted of 33 frames, which were shown at a slower rate (2.14 frames per second) than they were shown in the moving condition (25 frames per second), while the total stimulus duration was kept unchanged (two 15-s trials). All 33 frames were shown once within each of the two trials. A slowdown in the presentation speed of the same image sequence results in a reduction of apparent motion information. Therefore, the familiarization stimuli in the stop motion condition contained the same static information that infants see in the moving condition but with reduced motion information compared with the moving condition. If the faster learning of faces in the moving condition depends on seeing various static pictures, infants should show a novelty preference with 30 s familiarization duration in the stop motion condition, as well.

Method

Participants. Twelve 3- to 4-month-old infants (mean age = 111.6 days, range = 82 to 134 days; 7 females, 5 males) participated in this experiment. All were healthy Japanese infants who had a birth weight greater than 2,500 g.

An additional two infants were tested but were excluded from the analysis due to a side bias greater than 90%.

Procedure and stimuli. The procedure and stimuli were the same as those in the moving condition of Experiment 1, with the following exceptions. The familiarization stimuli consisted of the same 33 frames of static pictures used in the moving condition (Figures 2a and 2b) but shown at a rate of 2.14 frames per second. The order of the sequence was the same as that used in the moving condition but with each frame shown only once within each trial. All infants were familiarized with faces in the stop motion condition and were tested with two female faces with neutral expressions and without the external facial features shown (see Figure 2e and 2f and also Figure 4).

Results and Discussion

The mean total looking time from the two-familiarization trials is shown in Table 1. The mean total looking time in the test trials was 18.69 s for the stop motion condition. We again calculated a preference score for each infant. The mean preference score in the stop motion condition is shown in Table 1. A two-tailed one-sample *t* test (vs. chance level 50%) on the preference scores revealed that

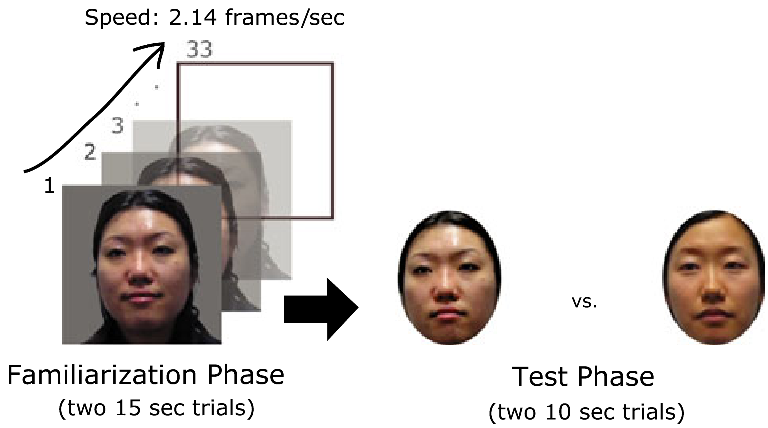

Figure 4. Illustration of familiarization and test stimuli used for the stop motion condition in Experiment 4.

the preference scores in the stop motion condition did not differ significantly from the chance level of 50%, $t(15) = 0.32$, $p > .1$, suggesting that infants could not recognize the familiarization face in the stop motion condition.

The results of this experiment demonstrated that even when all static images that comprised the moving event (Experiment 1) were shown in the same sequence, infants still did not discriminate a familiar versus novel static face with a new facial expression and hair cues eliminated. This argues for the importance of motion per se and eliminates the alternative explanation that a greater amount of static information provided by the multiple frames of the motion display was responsible for the difference found between the moving and static condition in Experiment 1. This provides compelling evidence for the representation enhancement hypothesis in infants' face recognition.

General Discussion

In this study, we compared infants' recognition memory for previously unfamiliar faces learned in a moving or a static condition. In Experiment 1, infants were familiarized with a face and tested with a different image of this face. Infants in the moving condition showed successful recognition of the face but infants in the static condition did not. Experiments 2 and 3 showed that infants did not successfully recognize learned faces until the duration of familiarization was extended to 90 s, even when the same image was used for familiarization and test. These results suggest that motion information promotes infants learning of faces and that infants learn faces faster in the moving condition than in the static condition.

Although infants spontaneously prefer to look at moving stimuli more than at static stimuli (Slater, 1995), the spontaneous preference for moving stimuli cannot explain our results. Because we used identical static faces for testing infants in both the moving and static conditions, the results are attributable only to the differences in the familiarization trials. Additionally, the total looking times during the familiarization trials did not differ between the moving and static condition, $t(22) = 0.56$, $p > .1$. Thus, we can conclude that the better performance of infants in the motion condition was not due to longer looking times at the familiarization stage.

Furthermore, the better performance shown by infants in the moving condition over the static condition cannot be explained by the fact that the familiarization stimuli in the moving condition contained a greater number of static pictures (33 frames) than those in the static condition (1 frame). Although infants in the stop motion condition (Experiment 4) viewed the same number of static pictures as in the moving condition, they did not show a preference for either the familiar or novel face. The results from the stop motion condition suggest that the better performance in the moving condition is not due to seeing many static pictures of the familiarization face, but rather, to seeing the familiarization face in motion.

Putting the results from this study into a more theoretical context, O'Toole et al. (2002) proposed two nonmutually exclusive hypotheses about the possible role of motion information in face recognition. The *supplemental information hypothesis* posits that motion information can contribute to face recognition via the processing of dynamic identity signatures that capture facial movements characteristic to an individual (e.g., a way of smiling). The *representation enhancement hypothesis* posits that motion information contributes to face recognition by enhancing the perceptual processing of faces via structure-from-motion analyses, thereby allowing the formation of a richer representation of facial structure.

The study of Spencer et al. (2006) provides evidence for infants' use of motion in a way that is consistent with the supplemental information hypothesis. Specifically, because Spencer et al. did not vary the facial structure of the stimuli presented in the habituation and test parts of the experiment, infants discriminated individuals based on idiosyncratic motion information alone.

This study demonstrates a complementary role for motion in a way consistent with the representation enhancement hypothesis. Infants who learned a face in motion later recognized a static picture of the face better than infants who learned the face from a static presentation. Our finding suggests that motion information facilitated infants' ability to construct a representation of the facial structure. This is consistent with the representation enhancement hypothesis. When considered together, the finding of Spencer et al. (2006) and that of this study support both the supplemental information hypothesis and the representation enhancement hypothesis in the case of infants.

It is interesting to note that the two hypotheses have not been supported in the same way for adults. Although the supplemental information hypothesis has been supported consistently in several studies on the recognition of familiar faces (e.g., Bruce & Valentine, 1988; Lander & Bruce, 2000; Lander et al., 1999; Lander et al., 2001), evidence for the representation enhancement hypothesis has been lacking despite experimental attempts to test for it (e.g., Christie & Bruce, 1998).

Apart from the typical memory-based face recognition tasks used in the studies mentioned above and reviewed in O'Toole et al. (2002), some recent studies reported an advantage of processing unfamiliar faces in a moving condition over a static condition (Pilz, Thornton, & Bülthoff, 2006; Thornton & Kourtzi, 2002). In Thornton and Kourtzi (2002), participants saw two faces, in turn, a "prime face" followed by a "target face," and were asked to decide if the identity of the target and prime faces matched. The prime face was either static or dynamic, whereas the target face was always static. Thornton and Kourtzi found faster reaction times for the moving prime condition, when the prime and target face image had the same identity but differed in expression or viewpoint.

Using a visual search paradigm, Pilz et al. (2006) reported a similar advantage in reaction time for moving when compared with static face presentations. In their study, participants were familiarized with two faces, one in a moving condition and the other in a static condition. Following familiarization, participants were asked to search for the familiarized faces and to indicate if one of them appeared in the arrays depicting multiple static faces. The faces shown in the familiarization and test periods differed in expression. Pilz et al. found faster reaction times for faces familiarized in the moving condition.

These findings are consistent with the representation enhancement hypothesis. Of note, however, the advantage found for moving stimuli was limited to a reaction time advantage of only about 30 ms for the prime matching task (Pilz et al., 2006; Thornton & Kourtzi, 2002) and about 300 ms for the visual search task (Pilz et al., 2006), with no accuracy advantage. Evidence in support of the supplemental information hypothesis has been obtained consistently, but only when the task is perceptually demanding (for review, see O'Toole et al., 2002; Roark et al., 2003).

When considered together, the effects of facial motion for recognition seem limited for adults in terms of both the representation enhancement hypothesis and the supplemental information hypothesis. The relatively limited effect of motion for face recognition could be due to the fact that adults' ability to perceive and represent faces is close to ceiling. Thus, adults have little difficulty in learning to recognize faces from static images. Notwithstanding, the findings for adult recognition stand in clear contrast to the facilitative effect of facial motion for recognition we find in infants. In this study, motion information promoted infants' recognition of the faces even for high-quality images. This suggests that motion information is more effective for young infants who are in the course of perceptual development. This view is consistent with the previous studies that have emphasized the role of motion information in infants' perception (Kellman, 1984; Kellman & Spelke, 1983; Otsuka & Yamaguchi, 2003; Owsley, 1983; Valenza & Bulf, 2007). These studies have reported that young infants perceive three-dimensional shape, illusory contours, and the continuity of partly occluded object behind the occluder in dynamic stimuli, but not in the static stimuli.

Although most studies of face recognition in infancy use static faces as the stimuli, faces in the everyday life are seen almost exclusively in motion.

Consistent with this study, other researchers have noted dissociations between infants' face recognition abilities with static and dynamic stimuli (Bahrick et al., 2002; Walker-Andrews & Bahrick, 2001). It might therefore be informative to probe infant abilities in ways that allow them to exploit motion information for achieving the task at hand. This may provide additional insight into understanding the developing face-processing skills of early infancy.

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