Infants' discrimination of faces by using biological motion cues

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Abstract. We report two experiments in which we used animated averaged faces to examine infants' ability to perceive and discriminate facial motion. The faces were generated by using the motion recorded from the faces of volunteers while they spoke. We tested infants aged 4 – 8 months to assess their ability to discriminate facial motion sequences (condition 1) and discriminate the faces of individuals (condition 2). Infants were habituated to one sequence with the motion of one actor speaking one phrase. Following habituation, infants were presented with the same sequence together with motion from a different actor (condition 1), or a new sequence from the same actor coupled with a new sequence from a new actor (condition 2). Infants demonstrated a significant preference for the novel actor in both experiments. These findings suggest that infants can not only discriminate complex and subtle biological motion cues but also detect invariants in such displays.

1 Introduction

The ability to perceive motion is a fundamental aspect of the human visual system. It plays a key role in proprioception and navigation (Nakayama 1985). It has been established that humans are very sensitive to 'biological motion', that is visual cues generated by a human or animal form in motion (Johansson 1973). For example, from simple point-light displays, observers can discriminate male from female walkers (Cutting et al 1978), and can discriminate their own gait from those of others (Beardsworth and Buckner 1981). Sensitivity to motion in point-light displays increases rapidly with the number of illuminated joints, and it has been suggested that the mechanisms that analyse biological motion adapt to the nature of the stimulus (Neri et al 1998).

Faces play an important part in human social interaction. Happiness or anger are expressed by changing facial expressions. With the exception of static images, it is rare to encounter a face that is not moving in some way (Pike et al 1997). Perceiving head and facial motion affords additional information that is not present in a static image. It has been shown, by means of point-light stimuli, that people are able to use motion information to perceive faces, but cannot accurately identify them (Bruce and Valentine 1988; see also Bassili 1979). Such point-light techniques demonstrate the usefulness of motion information in face perception. However, owing to the limited information available in point-light displays it is difficult to generalise from such findings to the recognition of real faces. For example, both spatial information about facial structure as well as dynamic information in the face are degraded in point-light displays. Consequently, recent studies have employed moving images of faces in order to study recognition of unfamiliar faces by people (eg Pike et al 1997).

Pike et al reported that, even when static cues can be used for recognition, recognition was more accurate for moving faces. They also reported that large head movements resulted in better recognition. This suggests that rigid head movements are a better cue for recognition than non-rigid affective motion cues. These gross side-to-side movements are thought to be an important source for deriving the three-dimensional (3-D)

structure of faces (Bruce and Langton 1994; Knight and Johnston 1997). However, Lander and Bruce (2003) have suggested that it is the non-rigid motion that attracts attention to faces in the first instance. The 3-D structure of the nose, cheeks, and eyes can not always be observed from expressive facial motion, but can be from facial rotation.

More recently, advances in computer graphics technology have enabled the combining of different motion cues with different objects. Hill and Johnston (2001) have extracted the facial motion from video sequences of actors and composed sequences of an animated computer-generated 'average' face using the motion information from those actors. They decomposed the motion information into rigid and non-rigid components; the rigid motion information corresponding to the nods and tilts of an actor's head, with the non-rigid components corresponding to the deformations involved in changes of facial expression. Using these stimuli, Hill and Johnston demonstrated that individuals could be discriminated by using facial motion alone and that men could be distinguished from women on the same basis.

Clearly adults are able to identify and categorise movements from the same person using biological motion. It is not clear if this is a sophisticated ability that is learned with experience, or if an infant's face and motion perception abilities are sufficient for perceiving biological facial motion at an early age.

Infants can detect motion by 1 month of age, but not necessarily motion direction. By the age of 12 weeks infants can discriminate the direction of motion over a wide range of velocities (Wattam-Bell 1996). The ability to perceive biological motion is dependent on the ability to integrate information about motion in different directions and at different speeds. This could be in place as early as at the age of 12 weeks.

The recognition of many important visual stimuli, such as facial expressions and gestures, is dependent on the ability to perceive non-rigid biological motion. Bertenthal et al (1987) have determined that by 5 months of age infants are able to discriminate and categorise the non-rigid motion of point-light walkers.

More recently, it has been shown that 3-month-old infants are able to categorise both animals and vehicles in dynamic point-light displays (Arterberry and Bornstein 2001). These findings provide evidence that the ability to detect complex biological motion develops early.

The early ontogeny of face-processing skills provides evidence that faces are special. It has been shown that within the first hour of life infants attend preferentially to face-like stimuli over other stimuli (Goren et al 1975; de Schonen and Mathivet 1989; Johnson and Morton 1991). The particular details of the face seem not to be important other than that they are configured so as to correspond with eyes and mouth. Newborns' tendency to attend to face-like stimuli may be all that is required to ensure that infants develop very specialised face-recognition abilities.

Infants are not only very sensitive to face configuration for the purposes of face recognition; they are also very sensitive to the numerous social cues presented by facial stimuli. Eye gaze is one such cue. Successful communication involves appropriate eye contract, and is thought to be essential for social and cognitive development (Kleinke 1986; Baron-Cohen 1994). For example, during social interaction it has been observed that 3-month-old infants smile less when an adult does not make eye contact (Hains and Muir 1996). Research of the development of eye contact has shown that 2-month-old infants tend to look at the eye region of the face more than at any other area (Maurer and Salapatek 1976), and that by the time infants are 4 months old they can even differentiate between faces with a forward gaze and those with an averted gaze (Vecera and Johnson 1995).

Changes in eye gaze involve not only movements of the eyes themselves, but also tilts and nods of the whole head. This highlights the importance of visual motion in face processing. There are many ways in which motion cues can be useful in face processing.

Motion can provide cues to 3-D shape via structure-from-motion (Ullman 1979), but it is uncertain how effective a cue this is given that most facial movements violate the rigid motion assumption necessary for perception of structure-from-motion. Previous experiments have suggested that the cues motion provides about shape may be important in face processing, but the difficulty of separating motion from spatial information makes it difficult to measure precisely the contribution of motion information.

As mentioned above, it has been demonstrated with computer graphic techniques that adults can discriminate identity and sex on the basis of facial motion (Hill and Johnston 2001). There is also evidence to suggest that infants are sensitive to facial expressions from a very early age (Montague and Walker-Andrews 2001), as they are to biological motion (eg Arterberry and Bornstein 2001). However, what is unknown is whether or not infants are sensitive to the motion component of these facial expressions.

The objective of this study was to test whether infants can use motion cues from natural facial gestures, expressions, and speech to make perceptual discriminations. The first aim of this study was to test whether infants can distinguish different sequences of facial motion; that is, sequences which differ because they are generated from different actors speaking different lines. The second aim was to determine whether infants can discriminate individuals on the basis of their facial motion. That is, whether infants, after familiarisation to one sequence, will look longer at a novel sequence from a second actor than to a novel sequence from the same first actor. Such a preference would indicate familiarisation not only to the specific motion pattern of one video sequence, but to the generic invariants in the facial motion of one actor, hence indicating discrimination of individuals on this basis.
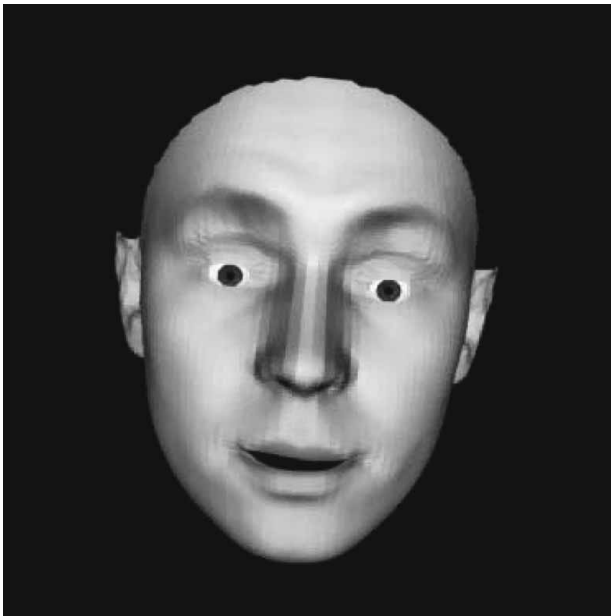
2 Method
2.1 Participants
Twenty-nine full-term infants (fifteen male and fourteen female, mean age 5 months 3 days, ranging from 3 months 29 days to 8 months 22 days; SD 1 month 3 days) took part in condition 1 of this study. Twenty-four full-term infants took part in condition 2 (twelve male and twelve female, mean age 5 months 10 days, ranging from 3 months 29 days to 8 months 22 days; SD 1 month 24 days). All of the infants had no ocular or other health-related problems at birth and at the time of testing. Infants were recruited either through local nurseries or an article in a local mother-and-child magazine. In condition 1, 55% of the infants were Caucasian, 31% were of Asian heritage, and 14% were of African heritage. In condition 2, the majority of infants were Caucasian (67%), with 25% of Asian heritage and 8% of African heritage. An additional seven infants were tested but were excluded from the analysis in condition 1 and seven in condition 2 owing to fussiness ($N = 4$ in each condition), parental interference ($N = 1$), tape error ($N = 1$), or experimenter error ($N = 1$).

2.2 Stimuli
The stimuli were derived from those used by Hill and Johnston (2001). Motion capture was used to animate a 3-D model of a computer-generated average head. Four different motion sequences were captured from each of twelve volunteers ('actors'), six male and six female. Each animation sequence was of an actor telling a simple question-and-answer joke to a confederate such as "Why do cows have bells? Because their horns don't work!". This activity was intended to elicit expressive and natural facial gestures, expressions, and speech. In order to capture the head and facial motion, 17 markers were placed on the head and face of each actor and were tracked, along with the pupils, with Famous vTracker (Famous Technologies, San Francisco) with two digital video cameras placed approximately 1 m in front of and 15 deg either side of the actors. The timing of the motion was captured as accurately as possible within the 25 frames s^{-1} temporal resolution.

It should be noted that the spatial features cannot be as accurate as the temporal ones given the differences between the shape of the actors' heads and the average head. Nevertheless, these shortcomings were the same for all the sequences, and so should not have prejudiced the results. All stimuli were identical at the start of each animation, and differed only in their motion sequence (see figure 1 for an example frame of animation). The average length of the original sequences was 7.2 s (SD 1.6 s). In order to make all sequences the same length, each sequence was reduced to 5.0 s and repeated three times making the total length for each sequence 15 s. It was necessary to ensure that all sequences were the same length to prevent infants responding to the length of sequences rather than their content. One sequence was less than 5 s in duration and was not included in the present study, leaving a total of 47 animations available for use.

Figure 1. Example frame of animation showing computer-generated average face after the method of Vetter and Troje (1997).

2.3 Apparatus

All of the infants were tested in a dimly lit room measuring 5.2 m × 3.1 m. The animation sequences were displayed on a plasma screen measuring 112 cm × 60 cm. A video camera was mounted 6 cm above and 5 cm behind the monitor and video taped the infants' faces. The stimulus presentation program used Cogent Graphics (developed by John Romaya at the Laboratory of Neurobiology at the Wellcome Department of Imaging Neuroscience, UCL, UK) and implemented in Matlab (Mathworks Inc., Natick, MA, USA).

2.4 Procedure

The infants were strapped into a modified baby car seat. The stimuli were viewed from a distance of 150 cm, thereby subtending an angle of approximately 37 deg × 22 deg. The parent or carer sat 100 cm behind the infant, well out of the line of sight. Parents were instructed not to interact with their infant during the testing. The laboratory enclosure was kept dark with the only light coming from the display screen, so that the only objects of interest within the infant's potential gaze were the stimuli. The infants were tested with a familiarisation/preferential looking paradigm (Fantz 1964). This procedure relies on the preference that infants exhibit for novel stimuli.

The standard procedure involves showing infants a number of exemplars from one category, followed by a preference test that pairs a novel exemplar from the familiar

category with an exemplar from a different unfamiliar category. However, owing to the complexity of the stimuli and the aims of the study, infants were familiarised with a single exemplar. This is not uncommon when using complex stimuli (eg Wattam-Bell 1996). The total time an infant's gaze is fixed on each stimulus during the preference test trials was recorded. If the infant's looking time at the exemplar from the novel category was longer than that for the familiar category, it can be concluded that the infant can discriminate the familiar and the novel categories.

A video camera mounted just above and behind the display screen was used to record and monitor the infant's gaze at all times. Looking time was measured by analysis of the video recording of each infant's face. At the beginning of each experiment, animated stimuli flashed on the screen at each of the stimulus locations to direct the infant's gaze to that location. This established a recorded standard of the position of the infant's head and gaze direction at each of the stimulus locations and was used to calibrate subsequent positions of an infant's head and gaze on the video record. Two experimenters ran the study: one operated the stimulus presentation program and the other monitored the infants' fixations.

The experiment comprised two conditions: the first (sequence discrimination) was used to determine whether infants could discriminate between the animated sequences; the second (motion identity discrimination) was used to determine whether infants could discriminate individuals on the basis of the animated sequences. The order of the sequence discrimination and the motion identity discrimination conditions was randomised.

In the familiarisation phase of the experiment infants were presented with a single animated face, selected at random from the 47 available, in the centre of the screen. There were 6 familiarisation trials in total, each lasting 15 s. A 15 s presentation time is typically used when familiarising infants to complex stimuli (Quinn and Eimas 1996; Quinn and Schyns 2003). At the beginning of each familiarisation trial and each test trial an animated stimulus flashed up at the centre of the screen to attract the infant's attention.

There were two test trials for each condition, each lasting 15 s, in which the left – right positioning of the test trial stimuli was counterbalanced across infants on the first test trial of each set of trials and reversed on the second test trial. In the test phase of the sequence discrimination the identical animation to the one shown in the familiarisation trials was paired with an animation showing a different actor reading a different joke randomly chosen from those available (see table 1). A significant preference for the novel sequence was taken to indicate that infants could detect the difference between sequences.

In the motion identity discrimination part of the experiment the familiarisation phase was identical to that of the sequence discrimination condition, with the proviso that the infants were familiarised with a different sequence than that used in the first part of the experiment. In the test phase, the infant was presented with a sequence of the same actor from the familiarisation phase but now telling a different joke paired together with a sequence of new actor telling a completely different joke (see table 2). These were chosen at random from those available. If an infant looks longer at the new actor, we can conclude that the infant can tell the difference between people based on their facial motion. We conclude this because the infant must see the familiar actor telling an unfamiliar joke as more similar than a novel actor telling a novel joke; otherwise the infant would not look longer at the novel actor. Using random combinations of sequences ensures that sufficient combinations of different actors and sequences that the preferences measured were for novel sequences and novel actors, not unusual actors or distinctive sequences.

Table 1. Example of the familiarisation phase and the test phase for the sequence discrimination part of the experiment.

Familiarisation

	(1) Actor A, sequence 1 (15 s)	
	(2) Actor A, sequence 1 (15 s)	
	(3) Actor A, sequence 1 (15 s)	
	(4) Actor A, sequence 1 (15 s)	
	(5) Actor A, sequence 1 (15 s)	
	(6) Actor A, sequence 1 (15 s)	

Sequence discrimination test	Left-hand stimulus	Right-hand stimulus
Trial 1, 15 s	Actor A, sequence 1	Actor B, sequence 3
Trial 2, 15 s	Actor B, sequence 3	Actor A, sequence 1

Table 2. Example of the familiarisation phase and the test phase for the identity discrimination condition.

Familiarisation

	(1) Actor C, sequence 2 (15 s)	
	(2) Actor C, sequence 2 (15 s)	
	(3) Actor C, sequence 2 (15 s)	
	(4) Actor C, sequence 2 (15 s)	
	(5) Actor C, sequence 2 (15 s)	
	(6) Actor C, sequence 2 (15 s)	

| Identity discrimination test	Left-hand stimulus	Right-hand stimulus
Trial 1, 15 s	Actor D, sequence 2	Actor C, sequence 4
Trial 2, 15 s	Actor C, sequence 4	Actor D, sequence 2

3 Results

3.1 Motion sequence discrimination

3.1.1 *Familiarisation trials.* Three observers measured infants' looking times to the familiarisation trials and the test trials. Interobserver reliability was high (Pearson $r = 0.99$). An infant's 'looking time' was the total period of time in which fixation was on the stimulus during the 15 s stimulus presentation. The mean looking time for the first block of three familiarisation trials was compared to the mean looking time for the second block of three. The mean times are shown in table 3. Because we tested infants aged between 4 and 8 months of age it was important to test for any age effects. A 2×2 mixed-design ANOVA (age broken into younger and older infants by trials: 1 to 3 months, and 4 to 6 months) revealed that there was no effect of age during the habituation trials ($p > 0.05$), but there was an effect of trials from the first three trials to the final three trials ($F_{1,22} = 7.3$, $p < 0.02$). The decline in looking time indicates that the infants habituated to the stimulus during the familiarisation trials. This effect of habituation typically occurs in experiments of this nature (Bomba and Siqueland 1983).

3.1.2 *Test trials.* A one-way ANOVA (age broken into younger and older infants by trials) on the test-trial data showed no age group effects ($p > 0.05$) (see figure 2 for a scatterplot of motion sequence preference by age). The total looking time of each infant across the two test trials to the novel stimulus (the novel actor speaking a novel

Table 3. Mean novel category preference scores in percentages for the sequence discrimination test condition and mean fixation times in seconds and standard deviations during the familiarisation phase of the sequence discrimination condition. Standard deviations are shown in parentheses.

Test phase	Familiarisation phase	
	trials 1 to 3	trials 4 to 6
Mean preference for novel actor novel sequence (% of looking time)		
56.60 (8.62)	14.04 (3.9)	9.71 (5.2)
$t_{28} = 4.09$, $p < 0.001$		
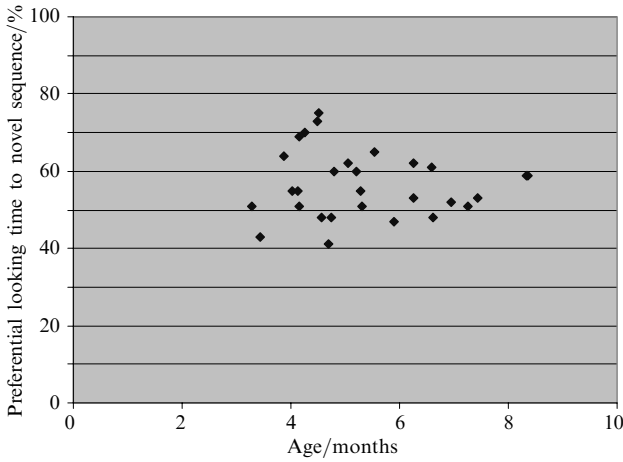
Figure 2. Scatterplot of motion sequence preference by age. A Pearson r correlation test revealed no significant correlation between age and preference, ($p > 0.05$).

statement) was divided by the total looking time to both test stimuli to give a percentage of fixation directed at the novel stimulus (see table 3; see table 4 for descriptive statistics of looking times to familiar and novel stimuli). A single-sample t-test revealed that infants displayed a reliable preference from chance (50%) for the novel sequence stimulus ($t_{28} = 4.09$, $p_{\text{one-tailed}} < 0.001$).

The preference for the novel motion sequence suggests that the infants could discriminate two motion sequences which were maximally different; that is, between *different* actors reading different jokes.

Table 4. Looking-time statistics for novel and familiar stimuli in the test trials of both conditions.

|	Mean	SD	Range
Motion sequence			
total looking time to novel stimuli/s	12.99	5.02	20.88
total looking time to familiarised stimuli/s	10.07	4.19	18.32
Motion identity			
total looking time to novel stimuli/s	12.73	4.68	17.60
total looking time to familiarised stimuli/s	8.95	3.50	12.24

3.2 Motion identity discrimination
3.2.1 *Familiarisation trials.* Three observers measured infants' looking times to the familiarisation trials and the test trials. Interobserver reliability was high (Pearson $r = 0.98$). The mean fixation times for the two blocks of three familiarisation trials are shown in table 5. A 2×2 mixed-design ANOVA (age broken into younger and older infants

Table 5. Mean novel category preference scores in percentages for the identity of motion discrimination test condition and mean fixation times in seconds and standard deviations during the familiarisation phase of the identity of motion discrimination condition. Standard deviations are shown in parentheses.

Test phase	Familiarisation phase	
Mean preference for novel actor novel identity of motion (% of looking time)	trials 1 to 3	trials 4 to 6
60.10 (12.30)	10.52 (5.07)	9.72 (4.75)
$t_{23} = 4.00$, $p < 0.001$		

by trials: 1 to 3 months and 4 to 6 months) revealed that there was no effect of age during the habituation trials ($p > 0.05$). There was an effect of trials, from the first three trials to the final three trials ($F_{1, 21} = 14.7$, $p < 0.01$), suggesting that the infants habituated to the familiarisation stimulus.

3.2.2 *Test trials.* A one-way ANOVA (age broken into younger and older infants by trials) revealed that there was no effect of age group ($p > 0.05$) (see figure 3 for a scatterplot of motion identity preference by age). The total looking time of each infant across the two test trials to the novel stimulus (this was the novel actor with the novel facial motion identity) was divided by the total looking time to both test stimuli (the familiar actor speaking a novel statement and the novel actor with another novel statement) (see table 5; see table 4 for descriptives of looking times to familiar and novel stimuli). The mean preference score for the novel stimulus was significantly greater than chance (50%) ($t_{23} = 4.00$, $p_{\text{one-tailed}} < 0.001$).
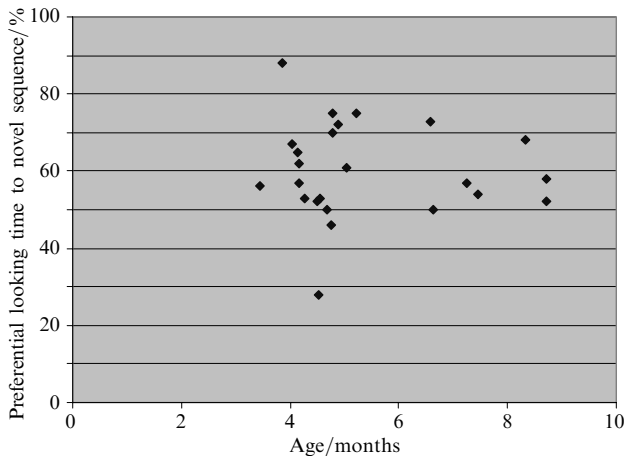
Figure 3. Scatterplot of motion identity preference by age. A Pearson r correlation test revealed no significant correlation between age and preference ($p > 0.05$).

4 Discussion

The discrimination of head-motion and facial-motion abilities of infants aged between 4 and 8 months was explored by a familiarisation/preferential looking technique. Two questions were addressed:
(i) Are infants able to discriminate between different complex facial motion sequences?
(ii) Are infants able to discriminate people on the basis of differences in their facial motion? That is, can they form an inclusive categorical representation of an actor's facial motion that excludes similar facial motion from other actors?

The results of conditions 1 and 2 indicate that infants aged between 4 and 8 months are able to discriminate between different facial motion sequences and between different actors.

As noted in the introduction, 12-week-old infants are able to discriminate the direction of motion over a broad range of different velocities (Wattam-Bell 1996). This ability would seem to be a prerequisite for perceiving biological motion. The results of the current study suggest that between the ages of 4 and 8 months infants' perception of motion is sufficiently sophisticated to allow the integration of speed and direction information over a considerable spatial and temporal extent. In order to use this information to discriminate sequences and actors, the precision of this biological motion perception must be high.

Previous research has demonstrated that infants aged 3 and 5 months are able to perceive and discriminate between stimuli using biological motion information (Bertenthal et al 1987; Arterberry and Bornstein 2001; Booth et al 2002). This is, however, the first time that young infants have been shown to be able to use biological motion to discriminate between different motion sequences derived from two different actors or to categorise two different motion sequences worn by the same actor as different from a third motion sequence worn by a second actor in the absence of cues to differences in underlying shape. Previously, adults have been shown to be able to identify individuals and to judge sex using facial motion (Hill and Johnston 2001). By isolating the rigid and non-rigid facial motion we have demonstrated that infants aged between 5 and 8 months can also use this type of information for discrimination and identification. The current results do not inform us of the relative weighting of the rigid and non-rigid information infants used. Hill and Johnston (2001) found that adults use rigid motion more for identification purposes and non-rigid motion for categorising sex. However, these differences may not be so apparent in infants. For example, Haith et al (1977) found that, when 2-to-3-month-old infants were presented with a live face moving from side to side and talking, the infants fixated significantly more to the eyes and central areas of the face than the edges of the face. It would be interesting to determine if infants made more use of non-rigid rather than rigid motion in this region in studies in which the two types of motion were separated.

In the current studies infants were discriminating between different motion sequences and not between different faces. However, there is a lot of research to suggest that infants are very sensitive to faces from an early age and can distinguish between static facial expressions by the age of 5 months (Bornstein and Arterberry 2003). However, when we encounter faces in the real world, more often than not they are dynamic. The primary role of facial motion is to facilitate communication through speech and expressions and to use this information to help guide social behaviour. This is particularly true for infants. During the first year of life, infants learn to differentiate a number of social behaviours through dynamic facial expressions (eg Walden and Ogan 1988). In addition, the exaggerated facial movements of infant-directed speech facilitate language development (Dominey and Dodane 2004). Recently, research has demonstrated that mothers also exaggerate infant-directed actions and that this may assist infants' learning of human action (Brand et al 2002). Taken together, it would seem that motion in general, and facial motion in particular, is a fundamental aspect of infant learning and development. Infants' ability to discriminate between and within facial sequences may have a biological and physiological basis and/or is a consequence of learning through experience.

We have shown that infants are sensitive to differences in motion that reflect differences in motion identity, although face shape remains constant. Normally, of course, a constant face shape implies a constant identity. This raises the question whether two sequences derived from two people are simply more different than two sequences derived from the same person telling two different jokes. A future experiment could address the question whether the ability infants have shown is face-specific or a general motion-processing ability. This could be tested by using inverted stimuli, since the face inversion

effects have been shown in biological motion (Hill and Johnston 2001). This would preserve motion differences while probably disrupting access to identity, at least in terms of meaningful facial motion. Nevertheless, the current results clearly show that infants are sensitive to the magnitudes of meaningful differences in facial motion.

References

Arterberry M E, Bornstein M H, 2001 "Three-month-old infants' categorization of animals and vehicles based on static and dynamic attributes" *Journal of Experimental Child Psychology* **80** 333 – 346

Baron-Cohen S, 1994 "How to build a baby that can read minds: Cognitive mechanisms in mind-reading" *Cahiers de Psychologie Cognitive* **13** 513 – 552

Bassili J, 1979 "Emotion recognition: The role of facial movement and the relative importance of upper and lower areas of the face" *Journal of Personality and Social Psychology* **37** 2049 – 2058

Beardsworth T, Buckner T, 1981 "The ability to recognize oneself from a video recording of ones movements without seeing ones body" *Bulletin of the Psychonomic Society* **18** 19 – 22

Bertenthal B I, Proffitt D R, Kramer S J, 1987 "Perception of biomechanical motions by infants: Implementations of various processing constraints" *Journal of Experimental Child Psychology* **37** 213 – 230

Bomba P C, Siqueland E R, 1983 "The nature and structure of infant form categories" *Journal of Experimental Child Psychology* **35** 294 – 328

Booth A E, Bertenthal B I, Pinto J, 2002 "Perception of the symmetrical patterning of human gait by infants" *Developmental Psychology* **38** 554 – 563

Bornstein M H, Arterberry M E, 2003 "Recognition, discrimination and categorization of smiling by 5-month-old infants" *Developmental Science* **6** 585 – 599

Brand R J, Baldwin D A, Ashburn L A, 2002 "Evidence for 'motionese': modifications in mothers' infant-directed action" *Developmental Science* **5** 72 – 83

Bruce V, Valentine T, 1988 "When a nod's as good as a wink: The role of dynamic information in facial recognition", in *Practical Aspects of Memory: Current Research and Issues* Eds M M Gruneberg, P E Morris, R N Sykes, volume 1 (Chichester, Sussex: John Wiley and Sons) pp 169 – 174

Bruce V, Langton S, 1994 "The use of pigmentation and shading information in recognizing the sex and identities of faces" *Perception* **23** 803 – 822

Cutting J, Proffitt D, Kozlowski L, 1978 "A biomechanical invariant of gait perception" *Journal of Experimental Psychology and Human Perception* **4** 357 – 372

Dominey P F, Dodane C, 2004 "Indeterminacy in language acquisition: the role of child directed speech and joint attention" *Journal of Neurolinguistics* **17** 121 – 145

Fantz R L, 1964 "Visual experience in infants: decreased attention to familiar patterns relative to novel ones" *Science* **146** 668 – 670

Goren C C, Sarty M, Wu P Y K, 1975 "Visual following and visual discrimination of face-like stimuli by newborn infants" *Pediatrics* **56** 544 – 549

Hains S M J, Muir D W, 1996 "Infant sensitivity to adult eye direction" *Child Development* **67** 1940 – 1951

Haith M M, Bergman T, Moore M J, 1977 "Eye contact and face scanning in early infancy" *Science* **198** 853 – 855

Hill H, Johnston A, 2001 "Categorizing sex and identity from the biological motion of faces" *Current Biology* **11** 880 – 885

Johansson G, 1973 "Visual perception of biological motion and a model for its analysis" *Perception & Psychophysics* **14** 202 – 211

Johnson M H, Morton J, 1991 *Biology and Cognitive Development* (Cambridge, MA: Blackwell)

Kleinke C L, 1986 "Gaze and eye contact: A research review" *Psychological Bulletin* **100** 78 – 100

Knight B, Johnston A, 1997 "The role of movement in face recognition" *Visual Cognition* **4** 265 – 273

Lander K, Bruce V, 2003 "The role of motion in learning new faces" *Visual Cognition* **10** 897 – 912

Maurer D, Salapatek P, 1976 "Developmental changes in the scanning of faces by young infants" *Child Development* **47** 523 – 527

Montague D P F, Walker-Andrews A S, 2001 "Peekaboo: A new look at infants' perception of emotion expressions" *Developmental Psychology* **37** 826 – 838

Nakayama K, 1985 "Biological image motion processing: a review" *Vision Research* **25** 625 – 660

Neri P, Morroni C, Burr D, 1998 "Seeing biological motion" *Nature* **395** 894 – 896

Pike G E, Kemp R I, Towell N A, Phillips K C, 1997 "Recognising moving faces: The relative contribution of motion and perspective view information" *Visual Cognition* **4** 409 – 437

Quinn P C, Eimas P D, 1996 "Young infants' use of facial information in the categorical differentiation of natural animal species: The effect of inversion" *Infant Behavior & Development* **19** 381 – 384

Quinn P C, Schyns P G, 2003 "What goes up may come down: perceptual process and knowledge access in the organization of complex visual patterns by young infants" *Cognitive Science* **27** 923 – 935

Schonen S de, Mathivet E, 1989 "First come first served: A scenario about the development of hemispheric specialization in early infancy" *Cahiers de Psychologie Cognitive* **9** 3 – 44

Ullman S, 1979 "Interpretation of structure from motion" *Proceedings of the Royal Society of London, Series B* **203** 405 – 426

Vecera S P, Johnson M H, 1995 "Gaze detection and the cortical processing of faces: Evidence from infants and adults" *Visual Cognition* **2** 59 – 87

Vetter T, Troje N F, 1997 "Separation of texture and shape in images of faces for image coding and synthesis" *Journal of the Optical Society of America A* **14** 2152 – 2161

Walden T A, Ogan T A, 1988 "The development of social referencing" *Child Development* **59** 1230 – 1240

Wattam-Bell J, 1996 "Visual motion processing in one-month-old infants: preferential looking experiments" *Vision Research* **36** 1671 – 1677

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