Long-Term Recognition Memory for Faces Assessed by Visual Paired Comparison in 3- and 6-Month-Old Infants

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It has been argued that operant conditioning is the only type of long-term memory present in infants prior to 6 months of age. In this study, memory for faces was investigated in 3- and 6-month-old infants with a visual paired-comparison task. In Experiment 1, infants were habituated to a face presented in different poses; recognition was assessed after a 2-min or a 24-hr retention interval. The 6-month-old infants and the male but not the female 3-month-old infants exhibited novelty preferences. A 2nd experiment showed that 3-month-old female infants were delayed relative to male infants in their face-processing ability rather than in their memory capacity. The results of Experiment 3 demonstrated in 3-month-olds an electrophysiological correlate of delayed recognition memory. These findings are discussed in the context of the neural systems thought to be involved in visual recognition memory (but not in procedural memory), namely the limbic system.

One crucial issue in developmental psychology is to understand when and how episodes taking place in infants' environments modify their cortical representations of the world and their expertise in various cognitive abilities. For several years, researchers have essentially attempted to describe the cognitive abilities that may guide learning and memory at the very beginning of life. Investigations of memory itself in this same early period of life were scarce. For instance, there are numerous studies of the development of face processing in infancy (for a review, see de Boysson-Bardies, de Schonen, Jusczyk, MacNeilage, & Morton, 1993). In contrast, there are almost no data available on memory for faces. Thus, it remains unclear when infants become able to memorize exemplars of several different faces, for how long they can retain these memories, how far memory for exemplars is involved in the early development of face-processing competencies, and whether the developmental path for face memory is the same as for object memory. To model the development of cortical functions and cogni-

tive competencies, it is important to establish milestones in the development of memory capacities during infancy. For instance, the models that describe how a competency such as face or object processing develops might differ according to whether and when young infants can memorize exemplars and episodes of faces (or objects) during this developmental period. The aim of this article is to establish some developmental landmarks of early memory systems.

Schacter and Moscovitch (1984) argued that declarative or explicit memory (see Squire, 1987) is not present in human infants under the age of about 8 months. Explicit memory, which includes what Tulving (1983) referred to as episodic and semantic memory, is generally thought to reflect memory for events and facts about which the participant is consciously aware and is impaired in amnesic patients with temporal lobe damage. Schacter and Moscovitch classified studies of infants into those that relied on a technique that is known to show an impairment in amnesic patients (declarative or explicit memory) and those that relied on a technique that does not show impairments in amnesic patients (procedural and implicit memory). The main source of knowledge on infant memory comes from Rovee-Collier’s (for a review, see Rovee-Collier, 1990) work in which the experimental paradigm, the mobile conjugate reinforcement, has been taken as a procedural memory process insofar as it is an operant conditioning situation that shares many of its characteristics with classical procedural-learning situations (e.g., learning to repeat the same response in front of the same stimulus, Schacter & Moscovitch, 1984).

One of the most popular techniques used to study recognition memory during infancy is the visual paired-comparison (VPC) task (Fantz, 1964), adapted for memory by Fagan (1973). In this task, the infant is presented with a stimulus for a brief familiarization period. Two stimuli are
thereafter presented: the familiar one and a novel one. Recognition of the familiar stimulus is assessed by a significantly longer duration of looking at the novel stimulus. Schacter and Moscovitch (1984) argued that VPC is a procedural memory task. However, Diamond (1990) postulated that the kind of recognition memory involved in VPC tasks is comparable to recognition memory as assessed by the delayed nonmatching to sample task. Thus, according to Diamond, VPC tasks involve memory processes that are similar to explicit memory. This interpretation is supported by recent data demonstrating that recognition assessed by VPC in amnesic patients is abolished when the retention interval is increased from 5 s to 2 min (McKee & Squire, 1993). Similarly, in infant monkeys as well as in adult monkeys with a medial temporal lobe lesion (the kind of lesion that is observed in amnesic patients and that has been used for years to reproduce in monkeys the human amnesic syndrome), a recognition deficit is observed in VPC testing with retention intervals as short as 10 s (Bachevalier, Brickson, & Hagger, 1993). Moreover, recently, Pascalis and Bachevalier (1995) demonstrated that visual recognition as assessed with a VPC task after a 30-s retention interval is abolished in adult monkeys with a neonatal lesion of the hippocampal formation and parahippocampal cortex. These later findings support Diamond’s assumption that recognition memory assessed by the VPC task should be considered declarative or explicit memory. On the contrary, there are no neuropsychological data available in human and nonhuman primates that would help to define Rovee-Collier’s (1990) mobile conjugate-reinforcement paradigm as testing a nonprocedural memory. The closest comparison would be with other tests of operant conditioning. Schacter and Moscovitch pointed out that operant conditioning on a schedule of continuous or conjugate reinforcement has been demonstrated in amnesic patients (Oscar-Berman, 1980) and in adult rats with hippocampal lesions (for a review, see O’Keefe & Nadel, 1978). The operant conditioning used by Rovee-Collier can also be compared with the 24-hr concurrent-discrimination task in which the same 20 object pairs are presented each day, one object in each pair is always correct, and the monkey is rewarded for grasping it. Monkeys with large medial temporal lobe lesions succeed in acquiring this associative habit (Malamut, Saunders, & Mishkin, 1984). Together, these results are consistent with the hypothesis that memory assessed by the mobile conjugate-reinforcement paradigm might be a type of procedural memory.

We now summarize the data that have been obtained in visual recognition memory with VPC during the first year of life in humans. With this method, Fagan (1973) demonstrated that 6-month-old infants were able to recognize a familiar stimulus (as inferred by a preference for a novel stimulus) after an interval of 2 weeks had intervened between the presentation of the familiar and novel stimuli. He was, however, unable to demonstrate recognition in younger infants even with a shorter retention interval. Cornell (1974) demonstrated the existence of recognition after a 2-min retention interval in 6-month-old, but not 5-month-old, infants. Pancratz and Cohen (1970) demonstrated that 4-month-old infants show a novelty preference immediately after the familiarization period but not when tested after a 5-min retention interval. More recently, Diamond (1995) observed a preference for novelty in 4-month-old infants when tested with a 10-s but not a 15-s retention interval. In contrast, 6-month-old infants showed a novelty preference with a 1-min, but not at 10-min, retention interval. Slater, Morison, and Rose (1983) have shown a novelty effect in 3- to 4-day-old infants tested immediately after the familiarization period. More recently, Pascalis and de Schonen (1994) found a novelty preference in 3-day-old infants tested with photographs of faces both immediately after the familiarization period and after a 2-min retention interval.

As emphasized by Bornstein (1985) and Nelson (1995), the assessment of recognition memory with the VPC task varies greatly according to task demands such as the length of the familiarization period and the category of stimulus used. For instance, the discrepancy between Pascalis and de Schonen’s (1994) findings with neonates and the findings of the prior studies that failed to demonstrate delayed recognition memory before the age of 6 months may have been a consequence of differences in habituation procedures. Pascalis and de Schonen defined a criterion for familiarization that might have been more suitable for young infants because it allowed them a longer period of familiarization than was used in other studies. Additionally, the nature of the stimuli may be important. For instance, 6-month-old infants have shown recognition memory after a 2-week delay for faces, but only after a 48-hr delay for patterns (Fagan, 1973). Event-related potentials (ERPs) have also been used to evaluate visual recognition memory. ERPs have the advantage of providing information about the neural events that underlie visual recognition memory and about cortical state maturation (e.g., a decrease in the latency of an ERP component with age can be taken as a sign of cortical maturation). Another advantage is that electrophysiological measures are, in certain circumstances, easier to obtain than behavioral measures. In the long term, ERP procedures can be used to determine whether the generator of the electrophysiological correlates of recognition observed in infants are the same as or different from those observed in normal adults or in prosopagnosics who exhibit only covert recognition of faces (Bauer, 1984; Tranel & Damasio, 1985; Renault, Signoret, Debruille, Breton, & Bolgert, 1989).

In most recognition studies using ERPs, infants are first familiarized with one stimulus and are then presented with alternating pictures of the familiar and novel stimuli; these stimuli can be presented equally often, or one can be presented more frequently than the other (e.g., the familiar stimulus can be presented on 80% of the trials with the novel stimulus presented on a random 20% of the trials). The virtue of presenting the novel and familiar stimuli with equal probability is that infants’ responses are uncontaminated by differential exposure to the two events during ERP recording. With ERPs, evidence of recognition memory has been demonstrated in 6-month-old infants (Nelson & Salapatek, 1986), but not in 4-month-old infants (Nelson & Collins, 1991, 1992; for a review, see Nelson, 1994). The lack of any
cortical sign of memory in 4-month-olds is in agreement with the assumption that recognition memory for episodes does not develop before 6 months of age. A caveat of this work, however, is that the familiarization period often resulted in infants seeing the familiar stimulus for only 10 or fewer total seconds (e.g., infants were presented with ten to twenty 500-ms presentations of the stimulus). Failure to observe any electrophysiological correlates of recognition memory, therefore, could have been a result of inadequate familiarization.

Overall, recognition memory has been demonstrated once (with the VPC task) for long delays at 6 months of age (Fagan, 1973) and as early as 3 days of age for a retention interval of 2 min (Pascalis & de Schonen, 1994). In addition, there is also electrophysiological (ERP) evidence of recognition memory in infants 6 months of age and older. Most of the studies with behavioral or ERP techniques failed to show recognition after a time interval greater than 1 min before the age of 6 months. During the first month of life many competencies change. The memory ability observed in a VPC memory task in neonates might be based on subcortical structures rather than on cortical functions. Failure to observe any recognition memory with a VPC test before the age of 6 months might be due either to insufficient habituation duration in the previous studies or to a change in cortical functioning at about the age of 6 months (for a discussion, see Nelson, 1995). The present study investigated whether it is possible to define in young infants a behavioral and an electrophysiological correlate of recognition memory for a time interval greater than 1 min.

We studied recognition memory for faces because changes in face-processing skills with age during the first year of life are now well documented. During the first weeks of life, infants recognize their mother's face and discriminate between photographs of adult faces, most probably on the basis of the outer contour of the head and hairline rather than the internal configuration (Bushnell, 1982; Bushnell, Sai, & Mullin, 1989; Pascalis, de Schonen, Morton, Deruelle, & Fabre-Grenet, 1995). In contrast, 4- to 5-month-old infants are able to recognize their mother's face from the internal configuration; that is, they process truly physiognomic aspects of faces (de Schonen, Gil de Diaz, & Mathivet, 1986; de Schonen & Mathivet, 1990). However, 4- to 5-month-olds do not recognize a face in very different poses (Cohen & Strauss, 1979), whereas 7-month-olds do (Fagan, 1976). Sai and Bushnell (1987) found that it is not until the age of 2 months that an infant looks longer at her or his mother's profile than at a stranger's profile, whereas preference for the mother's full face is present by 3 days of age. Note that this does not imply that the infant recognizes a face through different poses but only that he or she is familiar with both poses. It is only by about the age of 6–7 months that infants become able to recognize that a facial expression is the same despite changes in the intensity of the expression, identity of the model, and so forth (see Nelson & de Haan, 1996, for a review). The results of these studies thus show that face-processing abilities change between birth and 6–7 months of age. Therefore, as long as it is believed that nonprocedural memory emerges at about 6–7 months of age, it is legitimate to conclude that the development of face-processing abilities does not involve nonprocedural memory. However, if it is shown that nonprocedural memory is functional before 6 months of age, then it will no longer be possible to reject the assumption that this type of memory is involved in the development of face processing during the first half-year of life.

In Experiments 1 and 2, we investigated recognition memory with a VPC technique in 3- and 6-month-old human infants. A retention interval of 2 min or 24 hr was used, as was an infant-determined familiarization period. A retention interval of 2 min was used because (a) there is general agreement that the time course of short-term memory is about 1 min in adults (there are no data on human infants; Squire, 1992), (b) as mentioned above, amnesic adult patients familiarized with a visual stimulus do not recognize it after a 2-min interval (McKee & Squire, 1993), (c) Bachevalier et al. (1993) observed a deficit in visual recognition as assessed by VPC in infant monkeys after a 10-s interval. The current experiments examined whether long-term recognition memory for exemplars of faces is present before the age of 6 months (i.e., during the period in which face-processing skills develop) or whether it emerges only after these changes have taken place. In Experiment 3, we attempted to define ERP indexes associated with novelty preference in 3-month-old infants to ascertain whether the recognition ability observed at this age in Experiments 1 and 2 involved a cortical activity similar to that observed in 6-month-old infants.

**EXPERIMENT 1**

The purpose of this experiment was to determine whether 3- and 6-month-old infants can remember a face over a retention interval of 2 min or 24 hr. To be certain that infants were not habituated to a pattern but to a face, they were shown several different poses of the same face during habituation and yet a different pose during the test for novelty preference.

**Method**

**Participants**

Participants were recruited at birth in a maternity ward in Marseille, France. Only full-term (over 37 weeks of gestation) healthy infants with no known history of ophthalmologic or neurologic problems were tested. All infants were Caucasian and none had previously participated in another study.

Fifteen 6-month-olds (M = 185.0 days, SD = 5.6; 8 boys and 7 girls) were tested with a 2-min retention interval. Seven additional infants were not included in the final sample because of fussing or crying (n = 2) or technical problems in the video recording during the recognition test due to experimenter error (n = 5). Eleven 6-month-olds (M = 188.6 days, SD = 3.5; 6 boys and 5 girls) were tested with a 24-hr retention interval. Nine additional infants were not included in the final sample because of fussing, crying, or sleeping (n = 6) or technical problems (n = 3).

Sixteen 3-month-olds (M = 95.4 days, SD = 3.9; 8 boys and 8 girls) were tested with a 2-min retention interval. Eleven additional infants were not included in the final sample because of fussing and
crying \((n = 5)\), technical problems \((n = 4)\), or lateral bias during the looking behavior \((n = 2)\); a lateral bias was defined as looking exclusively at one side and the same side during both of the paired presentations of the novel and familiar faces. Twenty-two infants \((M = 91.8 \text{ days}, SD = 2.2); 10 \text{ boys and 12 girls}\) were tested with a 24-hr retention interval. Nine additional infants were not included in the final sample because of fussing, crying, or sleeping \((n = 6)\) or technical problems \((n = 3)\).

**Apparatus and Stimuli**

Each infant was tested at his or her home (to eliminate context novelty) at a moment defined by the mother as a period of the day when the infant was awake and alert. The infant sat on the parent’s lap, facing the midline of a presentation panel \((48.0 \text{ cm} \times 27.5 \text{ cm})\) located 30 cm away from his or her eyes. A Kodak Carrousel projector situated behind the presentation panel rear-projected the stimuli on one or both screens \((16.5 \text{ cm} \times 12.5 \text{ cm} \text{ each})\) situated on each side of the midline of the panel. The two screens were 6 cm apart. A video camera JVC GR-60 with a zoom lens was situated under the panel and recorded the infant’s face and eyes during all sessions. The experiment was electronically timed by a character generator that mixed elapsed time in 0.01-s increments directly onto the videotaped records.

The stimuli were color slides of the faces of four Caucasian women aged 25–28 years \((i.e., \text{ ages close to the majority of the mothers’ ages})\). The women wore black scarves to mask their hair and hairline contours and did not wear glasses or jewelry. The lines between the hair and forehead and between the hair and neck were modified directly on the slide with a black pencil to introduce variations of these lines from one picture to another of the same person. This eliminated the possibility of recognizing a face through the shape of the neck or through a particular detail of the line between scarf and forehead.

The faces were all photographed against the same black background and under the same lighting conditions. Each of the four faces \((A, B, C, \text{ and } D)\) was photographed 10 times, combining 5 different points of view \((\text{ full frontal view, right and left profiles, and right and left three-quarter view})\) with 2 different expressions \((\text{ neutral and smiling with the teeth visible})\). There were thus 10 different photographs for each of the four faces \((A1, A2, A3, \ldots, A10; B1, B2, B3, \ldots, B10; \ldots)\). Projected on the screen, the size of each face was 15 cm \(\times\) 11 cm.

In the familiarization task, each of the four faces was presented to an equal number of girls and boys in each of the two conditions \((2\text{-min and } 24\text{-hr retention interval})\). Each infant was habituated to the face of one woman \((A, B, C, \text{ or } D)\). A variable number of photographs was shown during habituation, depending on the number of trials the infant required to reach the habituation criterion. For example, some infants reached the criterion after six trials and thus saw six different poses; other infants reached the criterion after nine trials and thus saw nine different poses. For each face, the poses were presented in the same order so that an infant who required six trials saw the same five poses as the first five trials for an infant who required nine trials. The order of presentation of the poses varied depending on the face presented: \(A1, A2, A3, A4, A5, \ldots, A10, B3, B2, B1, B5, B4, \ldots, B10; C2, C1, C5, C3, C4, \ldots, C10; \text{ and so forth. Permutation of order of presentation was performed within each block of } 5 \text{ stimuli (i.e., within Stimuli 1–5 and within Stimuli 6–10)}\) so that all infants requiring only six trials were presented with the same poses whatever the identity of the face. Infants presented with Face A were presented first with a neutral-expression full frontal face, then with the neutral profile, the left smiling three-quarter view, the right smiling three-quarter view, and a smiling profile. Infants presented with Face B, were presented with the five same poses but in a different order: the smiling three-quarter view, the neutral profile, the neutral full frontal face, and so forth.

In the recognition test, the familiarized face was paired with a novel face. A new pose of the familiar face \((i.e., \text{ a pose that was not used in the familiarization session})\) was used in the recognition test and was paired with the same pose of a novel face. For all infants, the new pose was a smiling frontal view of the familiarized face. Not all possible pairings of faces were used because of differences in complexion, eye color, and general outer-head contour. To keep these characteristics \((\text{ complexion, eye color, and global head contour and surface})\) as similar as possible between the familiar and the novel stimuli so that the discrimination made by the infant should be based on physiognomic aspects, only two of the six possible pairings between faces were used; Face A was paired with Face B and Face C with Face D. Infants who were familiarized with A \((\text{ respectively C})\) had B \((\text{ respectively D})\) as the novel face, and those familiarized with B \((\text{ respectively D})\) had A \((\text{ respectively C})\) as a novel face.

**Procedure**

**Habituation**

A control procedure was used \((\text{ Horowitz, Paden, Bhana, } \& \text{ Selt, } 1972; \text{ Slater et al., } 1983)\). A slide was projected onto one of the two screens. The first trial began when the infant looked at the stimulus. An infant was judged to be looking at the stimulus when the reflection of that stimulus on the cornea was centered over the pupil. The trial ended as soon as the infant looked away from the stimulus for a continuous period of 2 s. Then, the stimulus was removed, a different pose of the same face was presented on the second screen, and the next trial began with the next look at the stimulus. In the third trial, again a different pose of the same face was presented. Trials continued in this way until the infant’s duration of looking on any three consecutive trials, from the fourth trial on, totalled 50% or less than the total of the first three trials.

**Recognition Test**

The recognition test occurred 2 min or 24 hr after familiarization. The test consisted of two pairings of the familiarized face with a novel face. For 6-month-olds, each trial lasted 10 s, and the left–right positions of the two stimuli were reversed across the two trials and counterbalanced across subjects. For 3-month-olds, the procedure was identical except that the duration of each trial was 20 s. This duration was defined on the basis of several previous studies showing that 20 s were necessary to offer an infant of this age the opportunity of looking at both stimuli \((\text{ Bornstein, } 1985)\).

**Results**

**Habituation**

**Six-Month-Old Group**

The average accumulated looking time was 65.9 s \((SD = 16.3)\) for infants tested with the 2-min interval. This average was not different from the fixation time for infants tested with the 24-hr interval \((63.0 \text{ s}, SD = 16.6)\), \(t(23) = 0.2, p = .89\). This looking duration was reached after an
The average accumulated looking time was 175.5 s (SD = 41.0) for infants tested with the 2-min interval. This average was not different from the fixation time of infants tested with the 24-hr interval. The total looking time during both trials did not differ for infants in the min group (M = 17.0 s, SD = 0.8) compared with infants in the 24-hr group (M = 16.6 s, SD = 1.1), t(24) = 0.6, p > .05, two-tailed. The total looking time during both trials did not differ for infants in the min group (M = 34.0 s, SD = 2.6) compared with infants in the 24-hr group (M = 30.3 s, SD = 3.8), t(38) = 1.7, p > .05, two-tailed.

### Novelty Preference

To facilitate a comparison across age, the raw data were normalized by dividing the looking time for the novel and familiar faces by the total available looking time for both faces (20 s for 6-month-old infants; 40 s for 3-month-old infants) to obtain the percentage of time spent looking at each face (shown in Table 1).

A mixed four-way analysis of variance (ANOVA) was performed on the normalized data with age (3 months or 6 months), sex (male or female), and retention interval (2 min or 24 hr) as the between-subjects variables and with novelty (familiar or novel) as the repeated measure. There was a significant effect of novelty on infants’ looking times, F(1, 56) = 23.25, p < .0001. None of the other main effects were significant, but there were significant interactions between sex and novelty, F(1, 56) = 4.52, p < .05, and among sex, novelty, and age, F(1, 56) = 9.89, p < .002. Examination of Table 1 suggests that these interactions were mainly due to

### Table 1: The Mean Percentage of Time Infants Spent Looking at the Novel and Familiar Faces by Age and Sex

<table>
<thead>
<tr>
<th>Participant group</th>
<th>Novel stimulus</th>
<th>Familiar stimulus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>3-month-olds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female infants</td>
<td>35.65</td>
<td>13.58</td>
</tr>
<tr>
<td>Male infants</td>
<td>53.34</td>
<td>16.22</td>
</tr>
<tr>
<td>6-month-olds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female infants</td>
<td>50.72</td>
<td>6.90</td>
</tr>
<tr>
<td>Male infants</td>
<td>48.08</td>
<td>8.73</td>
</tr>
</tbody>
</table>

Note. Percentages were computed by dividing the looking times for novel and familiar faces by the total available looking time (20 s for 6-month-olds and 40 s for 3-month-olds).
two-tailed. Female infants reached the habituation criterion after an average of 7.7 trials (SD = 1.6), which does not differ significantly from the performance of male infants, who reached the criterion after 8.0 trials (SD = 1.3), t(20) = 0.2, p > .05, two-tailed.

Discussion

In this experiment, we showed that 3- and 6-month-old infants were able to learn a face seen through different poses and to recognize it in a new pose after a 2-min or a 24-hr interval. At 3 months of age, however, recognition was shown only by boys. The results with 6-month-olds are consistent with previous findings (Fagan, 1973). Moreover, the results showed that what the 6-month-old infants and the 3-month-old boys learned in a photograph of a face was more than the specific picture; that is, they learned some physiognomic aspects of the face that enabled them to recognize a physiognomy from different views. Our results differ, however, from other published data on infant memory that failed to find long-term recognition memory in infants younger than 6 months tested with a VPC task. We return to this point in the GENERAL DISCUSSION.

The lack of recognition observed in the 3-month-old female infants is difficult to interpret. This sex difference may have been a transient phenomenon, however, because it was not observed in 6-month-old infants. There was no difference in the looking times during the habituation session between boys and girls that might account for a difference in visual preference during the VPC test. Thus, it might have been due to differences in developmental timing between girls and boys. For example, it might reflect a temporary developmental difference in memory competencies. This interpretation would be consistent with the results of a study on memory with infant monkeys, showing a sex difference in visual habit formation at 3 but not at 6 months of age (Bachevalier, Hagger, & Bercu, 1989). Another possibility is that it reflects a developmental difference in face-processing competencies. The fact that there was no difference in looking time during habituation argues against the assumption that boys and girls differ in their level of proficiency in face-processing skills. However, although girls might have reached the habituation criterion within the same time interval as boys did, they may not have picked up the same information from the several poses as the boys did. Girls might not have built a representation of the face from the different poses that provided them with sufficient cues to recognize the face under a new pose. They might have been habituated to a category of facial pictures instead of being habituating to one and the same face.

EXPERIMENT 2

To investigate whether the sex difference observed in Experiment 1 was related to a developmental difference in memory capacities or in face-processing competencies, a second experiment was conducted in which infants were habituated to only one view of a face instead of several views. We habituated a group of 3-month-old infants, using the same techniques as in Experiment 1, except that during habituation, infants saw only the full frontal view of one face. Recognition of the same face was evaluated after a 2-min retention interval in a VPC test. If, under these conditions, the sex difference vanished and girls exhibited recognition as did boys, then we would argue that the lack of recognition observed for 3-month-old girls in Experiment 1 might have been due to a sex difference in the developmental course of face processing, rather than in the developmental course of mesic capacities.

Method

Participants

Participants were fourteen 3-month-old infants (M = 97.5 days, SD = 2.3; 7 boys and 7 girls). An additional 14 infants were not included in the final sample because of fussing and crying (n = 6), technical problems (n = 5), or lateral bias during the retention test (n = 3).

Apparatus, Stimuli, and Procedure

The apparatus, stimuli, and procedure were the same as in Experiment 1 except that infants saw only the full frontal pose of
Results

Habituation

The average accumulated looking time for the stimulus was 200.0 s (SD = 47.0). The mean looking time for female infants was 195.5 s (SD = 60.0) and did not differ significantly from the mean looking time for male infants, 204.4 s (SD = 61.0), t(12) = 0.1, p > .1, two-tailed. There was no significant difference between these values and those observed in Experiment 1, unpaired t(42) = 1.4, p > .05, two-tailed, either in male infants, unpaired t(22) = 1.0, p > .05, two-tailed, or in female infants, unpaired t(20) = 0.8, p < .05, two-tailed. Female infants reached the habituation criterion after an average of 6.9 trials (SD = 0.7), which was not significantly different from the average for male infants, who reached the criterion after 7.7 trials (SD = 1.2), t(14) = 0.8, p > .05, two-tailed.

Recognition Test

Duration of Fixation of the Stimuli

During the two 20-s trials, infants looked for 16.6 s (SD = 1.9) during the first trial and for 17.3 s (SD = 1.5) during the second. These two values do not differ significantly, paired t(13) = 0.3, p > .05, two-tailed.

Novelty Preference

As in Experiment 1, the looking times for novel and familiar faces were converted to percentage of total available looking time (40 s for 3-month-olds). Three-month-olds looked longer at the novel face (M = 53.0%, SD = 12.9) than at the familiar face (M = 34.0%, SD = 10.4). A two-way mixed ANOVA was computed with sex (male or female) as the between-subjects variable and novelty (familiar or novel) as the repeated measure. Only the main effect of novelty was significant, F(1, 12) = 14.53, p < .003, revealing that both male and female infants behaved in the same way and looked significantly longer at the novel face during the recognition test.

The percentage of total looking time given to the novel stimulus was also computed for each infant (looking time for the novel stimulus divided by the looking time for the familiar stimulus). We used t tests to determine whether these values differed from that expected by chance (50%). Both male and female infants looked at the novel face significantly longer than expected by chance: for male infants, M = 58.7%, SD = 8.2, t(6) = 2.8, p < .03, two-tailed; for female infants, M = 61.0%, SD = 10.0, t(6) = 2.92, p < .03, two-tailed.

Discussion

We suggested that the absence of a visual preference for the novel face in 3-month-old girls tested in Experiment 1 might have been due to their inability to acquire a unitary representation of a face after observing distributed exposure through several poses of this face. The results of Experiment 2 showed that when the face was learned through one pose only and the retention test was performed with the same pose, girls did look longer at the new face after a 2-min interval, showing that they recognized the face previously seen. This result demonstrates that the absence of a visual preference in Experiment 1 was not a consequence of an immaturity of the memory system: Male and female 3-month-olds were able to recognize a novel stimulus after a 2-min interval. The sex difference observed in Experiment 1 might have been a consequence of a time lag between boys and girls in the development of their face-processing ability (or, more generally, in the development of their object-processing ability). The maturation of the face-processing (or object-processing) systems or of one of their components might occur later in girls than in boys.

EXPERIMENT 3

We have demonstrated in Experiments 1 and 2 that 3-month-old infants can recognize a stimulus after a 2-min delay and, at least for boys, after a 24-hr delay. These data contradict other published results, both from behavioral and electrophysiological studies (see Nelson, 1994, for a review). As was underscored previously, the failure in prior studies to observe evidence of remembering might have been due to a too brief exposure to the stimulus. In Experiment 3, we tested whether, if the familiarization time was sufficiently long, we could also demonstrate in 3-month-old infants the existence of electrophysiological correlates of visual recognition. The stimuli and the familiarization procedure were the same as in Experiment 1, and there was a 2-min retention interval between the end of habituation and the onset of the visual recognition test in which ERPs were recorded. If visual recognition in 3-month-olds is similar to that observed in 6-month-olds (Nelson & Salapatek, 1986), we should observe a positive wave correlated with presentation of the new face in a window of time starting at about 750 ms while the wave correlated with the familiar face is returning to baseline.

Method

Participants

Participants were recruited from birth records and birth announcements published in local newspapers in the Twin Cities, Minnesota, area. Only full-term, healthy infants with no known history of ophthalmological or neurological problems were tested. Fifteen 3-month-olds (M = 94.2 days, SD = 6.5; 8 boys and 7 girls) were tested. An additional 45 infants were not included in the final sample because of fussing or crying (n = 10) or because of data contaminated by body- or eye-movement artifacts (n = 35).

Stimuli

Stimuli were the same as in Experiment 1. The four different faces were each used with 4 infants except for one face that was used only 3 times.
**Electroencephalographic (EEG) Recording**

The EEG was recorded with Grass silver-silver chlorided electrodes referenced to linked ears. The electrodes were fastened to the infant's head using electrode paste, adhesive foam, and headbands. Electrodes were placed over midline occipital, parietal, vertex, and frontal scalp locations (Oz, Pz, Cz, and Fz) and over lateral temporal locations (T3, T4, T5, and T6) according to the international 10/20 system (Jasper, 1958), and a ground electrode was placed on the forehead. Scalp impedances generally averaged 5 KOhms. Because eye movements can cause artifacts in the EEG signal, the electrooculogram (EOG) was recorded with miniature bipolar electrodes placed above and below one eye in a bipolar transverse configuration. All bioelectrical signals were recorded with a Grass Neurodata Acquisition System, containing Model 12A5 amplifiers. The EEG gain was set to 20,000, and the EOG gain was set to 5,000. The bandpass was 0.1 to 30 Hz, with a 60-Hz notch filter engaged. Analog-to-digital (A/D) resolution was 12 bit.

**Procedure**

ERPs were recorded only during the recognition test, but electrodes were fitted to the infant's head before the habituation session. Each infant sat on the parent's lap facing a rear projection screen at a distance of 60 cm. Peripheral vision was occluded by side panels, and testing took place under dim illumination. The habituation session was identical to that of Experiment 1. When the habituation criterion was reached, a 2-min break was observed before the recognition test and the ERP recording session started. During the ERP session, a trained observer sat behind a screen and signalled the computer (by means of a push button) whenever the infant looked away from the presentation screen. In such cases, the stimulus was not projected. Each trial consisted of a 100-ms baseline, followed by a 500-ms presentation of the stimulus. EEG was sampled every 10 ms (100 Hz) throughout 1,800 ms, starting 100 ms before the onset of the event. The interstimulus interval varied randomly between 500 and 1,000 ms, and during this time the screen was blank. There were 60 trials in the ERP session during which the novel and familiar faces were presented randomly and with equal probability.

**ERP Data Reduction**

All trials during which the infant did not attend to the visual stimulus were rejected on-line. The remaining trials were digitized, edited for EEG and EOG artifacts by computer algorithm, and then stored on 44 MB Bernoulli cartridges. In an attempt to stabilize variability within and across conditions, we randomly selected a comparable number of trials (minimum of six) for the novel and familiar stimuli from the available set of artifact-free trials for each infant, and separate averages were formed. Grand averages were then computed by averaging these individual averages. On the basis of inspection of the infants' individual averages and the grand average as well as previous studies (Nelson & Collins, 1991, 1992), three time windows were identified to examine the ERP components: 200–500 ms, 750–1,200 ms, and 1,200–1,700 ms. Electrode Oz was analyzed separately with the time windows 200-500 ms, 750-1,200 ms, and 1,200-1,700 ms. For Oz electrodes, analyses of the area scores between 100 ms and 450 ms and between 500 ms and 800 ms because the morphology of the components differed from other midline electrodes. For reasons discussed in detail by Nelson and Collins (1991), we placed most emphasis on analyzing area scores because the intervals were so broad and contained relatively little peaked activity (in contrast to adult ERP responses). Area scores were computed by integrating the area beneath the sustained deflection within each time window in relation to the 100-ms pre-event baseline. These area scores were used in subsequent data analyses. When the area-score analyses revealed significant differences between conditions, we performed complementary analyses on peak amplitudes. Latencies to peak were not examined because generally peaks were distributed over time and, thus, identifying a peak latency would have been somewhat arbitrary.

**Results**

**Habituation**

The average accumulated looking time was 105.7 s (SD = 30.0). This value is not different from the fixation time observed in infants tested in the first experiment: both retention intervals, t(25) = 1.9, p > .05, two-tailed.

**Recognition Test**

**Area Scores**

Repeated measures ANOVAs were performed on the ERP area scores (and when appropriate, on the peak amplitudes) by using BMDP program 2V (Dixon, 1988). The p values were corrected with the Geisser–Greenhouse procedure when epsilon was less than .90. Separate ANOVAs were performed on the three intervals of interest: 200–500 ms, 750–1,200 ms, and 1,200–1,700 ms and for the midline electrodes (Pz, Cz, and Fz) and the lateral electrodes (T3, T4, T5, and T6). The Oz electrode was analyzed separately.

The grand average waveforms are shown in Figure 1. For the midline electrodes, a separate mixed three-way ANOVA with sex (male or female) as the between-subjects variable and with electrode (Pz, Cz, or Fz) and novelty (familiar or novel) as repeated measures was computed on the area scores for each of the three time windows. There were no significant effects in the 200–500 ms window. There was an effect of novelty in the 750–1,200 ms window, F(1, 13) = 4.66, p < .05, and in the 1,200–1,700 ms window, F(1, 13) = 8.65, p < .01.

For the lateral electrodes, a separate mixed ANOVA with sex (male or female) as the between-subjects variable and electrode (T3, T4, T5, or T6) and novelty (familiar or novel) as repeated measures was computed on the area scores of each of the three time windows. There were no significant effects in the 200–500 ms window or the 1,200–1,700 ms window. There was an effect of novelty in the 750–1,200 ms window, F(1, 13) = 4.67, p < .05, and in the 1,200–1,700 ms window, F(1, 13) = 4.67, p < .05.

For Oz electrodes, analyses of the area scores between 100 ms and 450 ms and between 500 ms and 800 ms revealed no significant effects.

On the basis of the results of the area-score analyses, we performed follow-up analyses on the peak amplitudes within each of the three windows specified earlier for the midline and the lateral electrodes.

**Maximum Peak Amplitude**

For the midline electrodes there was a significant effect of electrode for the 750–1,200 ms window, F(2, 26) = 4.35, p < .02, which occurred because the peak amplitude was
Figure 1. ERP grand averages in Experiment 3 derived by averaging across the participants' averages. The waveforms displayed are for the familiar face presented 50% of the time (solid line) and for the novel face presented 50% of the time (dashed line). Positive values are at the top of the vertical axes. Each waveform was shifted so that baseline (i.e., activity from −100 to 0 ms, not shown) was equivalent across the different conditions and electrodes. OZ, Pz, Cz, and Fz are midline occipital, parietal, vertex, and frontal scalp locations, respectively. T3 and T4 are left and right anterior temporal scalp locations, respectively. T5 and T6 are left and right posterior temporal scalp locations, respectively.

There was an effect of novelty for the 1,200–1,700-ms window, $F(1, 13) = 7.94, p < .015$. This difference occurred because the response to the novel face took the form of a positive slow wave, whereas the response to the familiar face was a return to baseline (see Figure 1). There were no significant effects for the lateral electrodes.

Minimum Peak Amplitude

For the midline electrodes, there was an effect of novelty in the 750–1,200-ms window, $F(1, 13) = 6.51, p < .03$. This effect reflects a greater negativity for the familiar than for the novel face. For the lateral electrodes, there was a significant effect of novelty in the 750–1,200-ms time window, $F(1, 13) = 6.16, p < .03$. This effect reflects the same differences as for the midline electrodes in that window.

Discussion

ERP evidence showed that 3-month-old infants recognized a face after a 2-min retention interval. The novel stimulus elicited a large positive slow wave, whereas the familiar stimulus elicited a return to baseline. It is generally thought that this type of positive slow wave reflects the electrophysiological correlate to the process of updating a memory representation for a partly encoded stimulus, whereas the return to baseline reflects the response to a well-encoded stimulus whose representation no longer requires updating (Nelson, 1994; Nelson & deRegnier, 1992). With the experimental paradigm used here, the two stimuli differed only by their degree of familiarization. They were presented an equal number of times during the retention test, and one stimulus was the familiar one for one group of infants, whereas it was the novel stimulus for another group. The electrophysiological differences, therefore, could have been related to recognition memory, not to sensitivity to how often a stimulus was presented or to particular characteristics of the faces used (see Nelson & Collins, 1991, for a discussion). Electrophysiological indexes and behavioral data thus converge to demonstrate recognition memory at the age of 3 months. Moreover, the electrophysiological correlates of recognition emerged about 750 ms after stimulus onset in 3-month-olds as well as in 6-month-olds.
(Nelson & Collins, 1991, 1992). Thus, there does not seem to be much difference in processing time between these two ages.

Given the sex difference observed in Experiments 1 and 2, we expected that ERPs recorded from female infants would be less mature than ERPs recorded from male infants. No electrophysiological correlates of a cortical maturation difference related to sex were observed in the ERP data. We cannot conclude, however, that there is no maturational gap between male and female infants around this age given that this lack of a difference might have resulted from the magnitude of individual variation in infants' ERPs, given the small number of participants.

GENERAL DISCUSSION

In these studies, we showed that 3- and 6-month-old infants were able to recognize a stimulus after retention intervals of 2 min and 24 hr as assessed by a VPC task following habituation to criterion with a control procedure. Moreover, we showed the existence in 3-month-old infants of a cortical electrophysiological correlate of this recognition memory after a delay of 2 min. Our results differ from Diamond's (1995) results despite the fact that the same habituation technique (control procedure) was used in both studies. Diamond demonstrated that 4-month-old infants tested with VPC showed recognition memory after a 10-s, but not a 15-s, retention interval, whereas 6-month-olds showed recognition memory after a 1-min, but not a 3-min, retention interval. The only difference between Diamond's procedure and ours was in the nature of the stimuli. Diamond used moving stimuli during both familiarization and VPC, whereas we used static stimuli. From studies on visual perception in infancy, there is no reason to believe that recognizing an object animated with a continuous movement would be different from recognizing an object in a static view (for a review, see Slater, 1989). Another possibly more important difference is that Diamond used objects, whereas we used faces. It may be that memory for faces develops earlier than memory for other objects. An advantage for faces could stem from infants' greater interest in faces relative to other objects, from infants' greater expertise with faces that result in "traces" that are easier to reactivate, or from developmental independence of face-processing and face-memory systems relative to object-processing and object-memory systems.

It is difficult to distinguish among these interpretations. Arguments in favor of the specificity of face processing have been suggested on the basis of adults' performance and brain imaging (for a review, see Gross & Sergent, 1992). However, any specificity–modularity of face processing might result from interactions between brain development and experience. Thus, studies of adults' processing of faces do not provide information about the specificity of the system in infancy. There are two results from studies of infants' processing of faces that are relevant to this question. First, neonates visually track a moving face with the features naturally arranged farther than they track one with the features scrambled (Goren, Sarty, & Wu, 1975; Johnson & Morton, 1991). Johnson and Morton (1991) called the system responsible for the preferential responses to faces observed in newborn infants CONSPEC. Pascalis et al. (1995), however, provided some experimental support for the idea that processing of the identity of individual faces during the first month of life is performed by a system that is not CONSPEC, even though CONSPEC may help the neonate to visually attend to faces. Second, individual face processing in 4- to 9-month-old infants is performed better by the right than by the left hemisphere. This is the same pattern of hemispheric difference observed in adults, suggesting that there may be specific face-processing mechanisms in the right hemisphere by this age (de Schonen, Deruelle, Pascalis, & Mancini, 1993; de Schonen & Mathivet, 1990; de Schonen et al., 1986). However, this hemispheric difference in face processing might be caused by a more general-purpose right hemisphere system for configural processing of patterns and faces (Deruelle & de Schonen, 1991, 1995) rather than by a specific face-processing system (de Schonen et al., 1993). Processing of objects may depend more on nonconfigural encoding, which may develop more slowly than configural encoding because of the slower development of the left compared with the right temporal cortex. Thus, memory for faces can develop earlier than memory for objects even if there is not a specific system for processing facial identity because of (a) the attentional bias introduced by CONSPEC and (b) the earlier development of configural processing (see de Schonen & Mathivet, 1989).

If this maturational difference between the two hemispheres were still present at the age of 3 months, we would expect a right–left difference in the ERPs recorded in 3-month-olds. However, no hemispheric differences in ERPs were observed in Experiment 3. One explanation is that this kind of cortical maturational difference is too subtle to be visible in ERPs unless specific techniques are used (e.g., high-density recordings and dipole localization procedures). Another explanation is that by 3 months of age, there is no more maturational difference between right and left cortices and only the behavioral consequences of the greater expertise with faces can be observed temporarily. In either case, the hypothesis that the difference between Diamond's data and ours might have been due to a difference in right–left cortical maturation rate or to a difference in the level of expertise with objects and faces can be neither rejected nor accepted.

The results of Experiments 1 and 2 show that the sex difference in novelty preference at 3 months of age is not related to a difference in memory skills but rather to a difference in face-processing skills. Girls might temporarily lag behind boys because of a delay in the development of face-processing skills. This time lag vanishes by the age of 6 months. Temporary sex differences have been demonstrated in many other studies on visual perception. In general, however, boys lag behind girls (Bushnell et al., 1989; de Schonen & Mathivet, 1990; Held, Birch, & Gwiazda, 1980; Pascalis et al., 1995). The sex difference observed in our data might have been due to a difference in the time table of cortical maturation of the right hemisphere, with male infants ahead compared with female infants. However, the
ERP data did not reveal any maturational difference between male and female infants, and there was no interaction between the sex and electrode variables. Nevertheless, small maturational differences between male and female infants might have been masked by the size of interindividual maturational differences in the relatively small sample.

In any case, results of Experiments 1 and 2 showed that the age of 3 months is a period of development in which face processing is changing. Experiment 2 showed that, nevertheless, memory for individual faces as assessed by VPC is functioning even at this age. Some arguments (see the introduction) support the assumption that recognition memory, when assessed by VPC, might be subserved by structures of the medial temporal lobe (Bachevalier et al., 1993; Brickson & Bachevalier, 1984; Diamond, 1990; McKee & Squire, 1993; see Nelson, 1995, for a review) and possibly specifically the hippocampal formation and parahippocampal cortex (Pascalis & Bachevalier, 1995). We are therefore inclined to conclude that memory processes present in 3-month-old infants are of the kind that involves the medial temporal lobe.

Pascalis and de Schonen (1994) showed that neonates exhibit a novelty preference in a task similar to that used in Experiment 2 (with a 2-min retention interval). Is this recognition memory the same as that demonstrated in the present experiments with 3- and 6-month-olds? At present, there are not sufficient data on memory performance in the period between birth and the age of 3 months to allow any firm conclusion. As long as it was believed that recognition memory as assessed by VPC emerged only at about 6 months of age, it was possible to believe that only procedural memory was functioning and that memory for exemplars of objects, faces, or events was not involved in the development of cognitive competencies. Our results do not demonstrate that memorized exemplars of faces and their cortical correlates are involved in the development of face processing; however, they do show that this possibility can no longer be rejected.

CONCLUSION

The present results confirm, with a method totally different from the operant-conditioning technique used by Rovee-Collier (1990), the existence of long-term recognition memory after a 2-min and a 24-hr retention interval in 3-month-old infants (Rovee-Collier & Sullivan, 1980; for a review, see Rovee-Collier, 1990). Thus, contrary to what has been suggested by other authors, visual recognition memory as assessed by VPC is present as early as the age of 3 months. The extent to which this memory ability is specific to faces remains to be determined. Also, we demonstrated that recognition memory as assessed by VPC involves the hippocampal formation and adjacent cortex. On the basis of the behavioral and electrophysiological data reported here, we can say that the kind of memory called pre-explicit memory by Nelson (1995), which is believed to be different from procedural memory, is present at least from the age of 3 months in human infants. We conclude that long-term memory for exemplars of faces and the cortical correlates of this type of long-term memory cannot be excluded from the mechanisms of development of face-processing skills. It is important now to determine whether and how this early long-term memory is indeed involved in the elaboration of cognitive skills such as face processing.

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