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Through the Eyes of an Infant
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Developmental Changes in Visual Scanning of Dynamic Faces and Abstract Stimuli in Infants

Abstract
The characteristics of scanning patterns between the ages of 6 and 26 weeks were investigated through repeated assessments of 10 infants. Eye movements were recorded using a corneal reflection system while the infants looked at two dynamic stimuli: the naturally moving face of their mother and an abstract stimulus. Results indicated that the way infants scanned these stimuli stabilized only after 18 weeks, which is slightly later than the ages reported in the literature on infants’ scanning of static stimuli. This effect was especially prominent for the abstract stimulus. From the 14-week session on, infants adapted their scanning behavior to the stimulus characteristics. When scanning the video of their mother’s face, infants directed their gaze at the mouth and eye region most often. Even at the youngest age, there was no indication of an edge effect.

Chapter 2

INTRODUCTION

When infants are born, their motor skills are very limited, and the fact that they have very little control over their limbs restricts the way in which they are able to explore the world around them. The oculomotor system – unlike other motor systems – approximates its mature state several months after birth. The infant exercises this system every day from birth on. This makes vision one of the most important channels through which babies learn about the world surrounding them. However, during the first months of life, eye movements and visual acuity are also subject to certain constraints. For example, during the first month, eye movements are often inaccurate and unreliable (Atkinson, 1992), and infants of 1 to 3 months of age who are fixating a salient stimulus often have difficulty shifting their gaze away toward another interesting stimulus (Stechler & Latz, 1966; Butcher, Kalverboer, & Geuze, 2000; see Chapter 3).

Development of Scanning

Scanning is the pattern of eye movements to fixate different parts of an object of examination. As the visual system matures, the characteristics of infants’ scanning patterns change. At birth, infants already show complex active scanning behaviors, but they often fail to direct their gaze toward a stimulus present in their field of vision (Haith, 1980; Bronson, 1990a). Around the age of 1 month, babies tend to look especially at edges or outer contours of a stimulus pattern, but they mostly ignore the inner parts of a stimulus (Salapatek, 1975; Milewski, 1976). They also have the tendency to fixate single locations of stimuli for long periods, a behavior that has been referred to as “staring” (Bronson, 1996). Infants of 2 months of age scan more locations and different features of stimuli (Bronson, 1982, 1990a, 1996; Salapatek & Kessen, 1966; Leahy, 1976).

The changes in infants’ scanning behavior can be described as a gradual transition to adult-like scanning (Bronson, 1994). As infants grow older, they engage more frequently in an advanced scanning mode, showing more brief fixations and more extensive scanning, whereas the infant-like way of scanning – characterized by periods with extremely long fixations directed to single salient features – becomes less prominent. Around 3 months, infants can make accurate, efficient eye movements. Salient features in the environment still attract their gaze, but they have gained volitional, strategic control over their scanning behavior (Bronson, 1994).

It is known from studies with adults that characteristics of the stimuli influence the way they are scanned. Changes in the way of scanning have been shown to be related to physical components of the stimuli such as luminance or texture (Mackworth & Morandi, 1967; Antes, 1974; Buswell, 1935) but also to semantic aspects (Loftus & Mackworth, 1978) or familiarity (Althoff & Cohen, 1999) and experience (Chapman & Underwood, 1998). There are indications that infants adapt their scanning patterns to stimulus characteristics increasingly more during the first few months of life (Johnson
Developmental Changes in Visual Scanning

& Johnson, 2000). Further, it seems that stimulus characteristics can elicit more or less mature scanning behavior in young infants. For example, if the internal elements of a stimulus are moving, they are more likely to attract the gaze of even 1-month-old infants (Bushnell, 1979), whereas in infants of 13 weeks of age a flickering stimulus evokes a scanning pattern similar to that observed with a static stimulus at a much younger age (Bronson, 1990a).

Face Scanning

Human faces are among the most important stimuli in the visual environment of a baby. Infants are confronted with faces very frequently from birth on and show attraction for faces or facelike stimuli already at an early age (Fantz, 1961; Morton & Johnson, 1991). Moreover, faces are of large psychosocial significance for a baby because mostly they appear in sight and draw the infant’s attention in a situation of interaction and communication.

Infants’ reactions to faces have been studied frequently, and there has also been considerable interest in how exactly infants examine faces. Infants younger than 2 months of age show limited scanning mostly of the perimeter of faces, whereas infants older than 2 months become more likely to fixate the internal elements of faces. When looking at the internal features of a face, they pay most attention to the eyes (Haith, Bergman, & Moore, 1977; Maurer & Salapatek, 1976). The borders of the face have been shown to be attractive regions of the face even for infants of 2 or 3 months of age (Haith et al., 1977; Hainline, 1978), whereas the mouth is looked at quite seldom (Haith et al., 1977). Previous studies thus suggest a developmental shift from scanning directed at the edges of a stimulus to scanning of the internal elements similar to that described earlier for geometric stimuli. At least for schematic faces, there are indications that the effect of edge attraction might be less prominent if the internal features of the face are moving (Girton, 1979).

Young infants are usually exposed to faces in social situations. Adults’ (especially parents’) interactions with babies have been shown to be highly similar across individuals even from different cultures and to be characterized by elements like attracting attention and eye contact, displaying greeting responses, and making exaggerated facial movements and signals of pleasure (Papoušek & Papoušek, 1987). It is therefore remarkable that only very few studies have made use of moving or talking faces (e.g., Hainline, 1978), and when real faces have been used, they often were still faces (e.g., Maurer & Salapatek, 1976; Bronson, 1982).

The use of stimuli that are of limited ecological validity has been addressed and criticized frequently (Neisser, 1976; Schmuckler, 2001), as the generalizability of the obtained results is questionable. This study examines how infants scan naturally moving faces like those they are confronted with in daily life.
Chapter 2

Measuring Eye Movements in Infants

The technique of infrared corneal photography was first applied to human infants in the 1960s (Salapatek & Kessen, 1966; Haith, 1969) and always had to cope with a number of problems inherent to using a complex and highly sensitive technique with delicate and unpredictable subjects. The technical progress and the experience of the last 40 years have enabled several improvements of the original method, which enhance the quality and accuracy of the measurements. Examples are the increase of the sampling rate from 2 - 6 Hz to 30 - 60 Hz (Aslin, 1981; Hainline, 1981; Bronson, 1982) to improve the accuracy in determining fixation durations and the implementation of a calibration (Bronson, 1983; Harris, Hainline, & Abramov, 1981) to enhance the spatial accuracy of the measurement. Incorporating a head-tracker into the eye-tracking system now has reduced the need to restrain the infant’s head, which was quite unnatural and often distressing for the infant.

This study combines the recent improvements in infant eye-tracking techniques with an intense longitudinal design. It also demonstrates the limitations of measuring eye movements in young infants and reports ways of handling the emerging problems of optimizing the data acquisition and dealing with missing data in a longitudinal design.

Aims of the Study

Several studies have compared infants' attending to moving and static stimuli, and the attention-enhancing effect of stimulus movement has been described frequently (e.g., Wilcox & Clayton, 1968; Tronick, 1972; Carpenter, 1974). There are also indications that infants might scan moving stimuli in a different way than static displays (Bronson, 1990a; Johnson & Johnson, 2000). However, whereas the development of scanning of static stimuli has been studied widely, it is still unknown how infants scan non-static stimuli and how scanning of dynamic stimuli develops throughout infancy. Thus, our first goal was to describe infants' scanning of dynamic stimuli and its development during the first few months of infancy. We chose to investigate infants' scanning of two different dynamic stimuli: the infant’s mother’s face as it moved in a natural way and an abstract stimulus. The scanning of these two stimuli was examined between 6 and 26 weeks of age because this age period covers an interval in which the infant’s oculomotor and visual system is changing rapidly (see e.g., Atkinson, 1984). Infants were examined with intervals of 4 weeks between test sessions to provide enough measurements to precisely describe the development on the one hand but prevent possible training and habituation effects on the other.

As sketched above, stimulus characteristics might influence the way stimuli are scanned already in infancy. Thus, our second goal was to examine whether the scanning patterns elicited by a moving face differed from the scanning patterns elicited by an abstract dynamic stimulus and from which age on infants tailored their scanning behavior to the characteristics of the stimuli. To obtain an abstract stimulus that was
comparable to the face video with regard to movement, colors, and luminance, but which had no facelike characteristics, the video of the mother’s face was scrambled. As stimulus characteristics might not only influence the way infants scan them but also how these scanning patterns evolve, we also investigated whether there were differences in how the scanning patterns of the mother and the abstract stimulus developed during the first few months of life.

The third goal of the study was to determine which regions of the face were frequently looked at and how this developed as infants were growing older. The question was whether the patterns of scanning of faces found in earlier studies that used less ecologically relevant representations of faces or even static faces are also found for naturally moving faces. We expected that the movement of highly salient internal features would reduce the clear effect of edge preference in very young infants and the frequency of edge fixations in the older infants. We also expected that it would lead to a more equal distribution of fixations over the regions of the face around the different internal features in contrast to results of earlier studies that have emphasized the infants’ preference to fixate the eye region.

**Method**

*Participants*

Ten infants (5 girls; 5 boys) participated in the longitudinal study. The mothers of the infants were contacted through childbirth education classes, midwives, or gym classes. Parents were told about the course and goals of the study and gave their written informed consent. The research was approved by the local Medical Ethics Committee.

All infants had been born after a gestation period between 37 and 42 weeks, had a birth weight above 2800 g, and no history of pre- or perinatal complications. All infants scored within their age range on the Bayley Scales of Infant Development (BSID-II; Bayley, 1993) at 12 and 24 weeks of age. Measurement sessions were conducted at 6, 10, 14, 18, 22, and 26 weeks, calculated from the due date. Mean ages were 46.7 days ($SD = 3.8$), 73.0 days ($SD = 2.4$), 102.2 days ($SD = 3.4$), 130.2 days ($SD = 2.3$), 158.0 days ($SD = 3.4$), and 186.7 days ($SD = 4.4$).

If a measurement session was unsuccessful because the infant was not in the required state of alert wakefulness or other problems occurred, a new appointment was made. Despite attempts to retest, data for an additional 10 infants were not included because fewer than 5 of their 6 test sessions could be analyzed due to fussiness, crying, or technical problems. Nine of the 10 infants included in the analysis completed all 6 test sessions; one infant completed 5 sessions.

*Procedure*

Appointments were made at a time of the day when the mothers expected their baby to be awake and able to stay alert for about half an hour. After arriving at the
laboratory, the infant was given some time to get used to the new environment. When the infant was in state 3 or 4 of Prechtl’s scale of alertness (awake, eyes open, some spontaneous movements, no crying; Prechtl & Beintema, 1964), the experiment was started.

**Apparatus**

To carry out the assessments at the different ages under the same circumstances, a setup suitable for infants from 1 to 6 months of age was developed. The infant was seated in an infant chair in front of a 21 inch monitor at a distance of 35 cm. The seat was tilted backwards (about 45 degrees) to provide enough support for the younger infants and to keep the older ones from leaning forward. The infant’s head was slightly stabilized, especially when the infant was young, but head-movements were not severely restricted to avoid distressing the babies and to allow them a natural way of moving while looking at the stimuli.

Only the screen of the monitor was visible. The frame and the other equipment necessary to run the experiment and to record eye movements were concealed behind a gray curtain, which filled approximately 180 degrees of the infant’s visual field. During the task, one experimenter stood behind the baby to support the infant’s head when necessary, while the second experimenter controlled the presentation of the stimuli and the measuring equipment. The baby’s face and the display visible to the baby were shown on a video monitor, which made it possible for the experimenter to watch the infant’s behavior while running the task.

**Stimuli**

Two dynamic stimuli were presented to the baby: a short video of the baby’s mother’s face, in which the mother was looking, smiling, and nodding to the baby as she would in a normal interaction, and an abstract moving figure. Both stimuli were in color. The video recording of the mother’s face was made during a preliminary visit of mother and baby to the lab, shortly before the sessions in which the data were collected began. The mothers were asked to start with an attention getting movement (like nodding or greeting) and then to continue in a way that felt natural to them. As infants are sensitive to other persons’ gaze direction during interactions (Hains & Muir, 1996), mothers were asked not to avert their gaze during the recording. The videos were digitalized for use in a computerized experimental design.

The abstract stimulus was derived from the digital video of the mother by carrying out a number of transformations in a graphic computer program (Corel PHOTO-PAINT 9), such that it no longer resembled a face. During the transformation the image of the mother was rotated, scrambled, and distorted. This frame-by-frame procedure ensured that the two stimuli used were comparable in terms of total dynamics, color, and luminance. One frame from each type of video is presented as a stimulus example in Figure 2.1.
Both stimuli had the same size and appeared against a gray screen. At the distance of 35 cm, the stimuli were 30 by 40 degrees in size. The luminance of both figures was approximately 50 lux in the center of the stimulus. Each stimulus was presented to the baby for 30 s. The order in which they were shown was pseudo-randomized.

**Measurement of Eye Movements**

The eye movements of the infants were measured using a corneal reflection eye-tracking system (ASL, model 504). The infrared remote camera was positioned on a pan/tilt base underneath the monitor at a distance of about 50 cm from the eyes of the infant. Eye position data were sampled at 50 Hz.

As the infants could move their head in a natural, relatively free way, their head position was tracked by a sensor, which was attached to a soft fabric hat and coupled to a magnetic head-tracker (Polhemus Fastrak). The head position data were used
constantly during the experiment to direct the remote camera, which recorded an image of the eye. The camera followed slow horizontal and vertical head-movements automatically and was also able to recover an eye-image quickly after a rapid movement or even a turn away from and back to the monitor. A video recording of the location of the current fixation superimposed on the video display allowed the experimenter to see where the infant was looking at all times.

As eye geometries have been shown to differ considerably between infants (Bronson, 1990b), every infant’s visual field was calibrated prior to each measurement session. The calibration stimulus was a flashing black-and-white concentric square that appeared on the monitor first in the top left and then in the bottom right corner of the area in which the abstract and the face stimulus were presented. The calibration stimulus was accompanied by a short quacking noise. The experimenters judged whether the baby was fixating the stimulus before carrying out the calibration.

Each calibration was tested to evaluate the quality of measurement during the experimental session. A spiral of about 12 degrees in diameter was presented to the infant on the monitor. The spiral moved across the gray screen and stopped at five different locations (the four corners and the center of the subsequent stimulus) where it shrunk to a size of about 3 degrees with a gaudy dot in the center. As the baby followed the moving stimulus and fixated the points at which it was still, the experimenter could watch the infant’s focus of gaze on the monitors and judge the quality of measurement. If necessary, the calibration procedure was repeated.

Analysis

Eye position data. To determine the number and length of fixations during stimulus exposure, saccades, which naturally mark the beginning and end of a fixation, had to be identified from the eye position data. The displacement was calculated from the horizontal and vertical eye position data using Pythagoras’s theorem and smoothed with a 5-point window (100 ms). The onset of a saccade was defined as (a) pupil diameter above 0 as an indication of a valid signal and (b) change in fixation position larger than a threshold value. The threshold value adopted for saccade onset in this study was a mean displacement of .6 degrees per sample point over 3 sample points (60 ms). This is equivalent to an eye movement velocity of 30 degrees/s.

Experience in using eye-tracking methods with infants has taught us that the data yielded by an eye-tracker are often incomplete or contain artifacts. Examples of frequently occurring problems are missing data due to pupil loss after a posture change or a rapid head-movement. Artifacts can be caused by fussing, crying, or screwing up the eyes.

Behavioral coding. To correct errors and complete the data set, the video recordings of each infant’s face were coded off-line. They were played back half-frame by half-frame (20 ms intervals) and compared with the available information from
the eye-tracker data files. Looking with narrowed eyes was included if a part of the pupil was visible. The coding was carried out by two observers. The interobserver reliability (across subjects and across infants’ ages) for the classification of an eye movement indicated by the eye-tracker as a real eye movement versus an artifact was 94.7%. For detecting an eye movement in the absence of an eye-tracker signal, it was 96.9%. The reliability between observers for the onset and the length of an eye movement was 92.5% and 94.6%, respectively. Finally, for judging whether the infant was looking at the stimulus display or not, the agreement was 92.0%. With these corrections and completions on the basis of the videotaped eye movements it was possible to obtain complete data on whether the infant was looking to or away from the stimulus display and on the relative displacement of the eyes. The latter were used to determine the number and duration of fixations.

Coding of location of fixations. As the test of calibration carried out before every stimulus presentation revealed, the quality of eye-tracker measurement differed considerably across sessions. When the calibration was successful and allowed a reliable measurement of absolute eye position, data on the actual location of the fixations on the respective stimulus could be collected.

The location of the fixations was scored off-line by a single observer, using the video recordings of the stimulus display with the sequence of the infant’s fixations superimposed on it. Every stimulus was divided into a number of zones, and each fixation was – if possible – assigned to one of these areas. For the face stimulus, the categories were “eyes”, “mouth”, “edge” (including the hairline and the ears as well as the lower edge of the face), “background”, and “body” (neck, hair lying on the shoulders). The zones were determined separately for each stimulus using grid lines (for an example, see Figure 2.2). As the stimulus was moving, the areas could
change with time. Fixations were categorized as “missing” when it was impossible to determine where on the stimulus the baby was looking, and as “off” when gaze was averted from the stimulus.

The data on the location of fixations of the abstract stimulus were not analyzed. To make the movement, color range, and luminance of the two stimuli as similar as possible, each infant had been presented with an abstract stimulus derived from the video of his or her own mother. The location and movement dynamics of the core features of the resulting stimuli were too different from each other to incorporate them in a useful way into a common coding scheme.

Statistical Analysis

Three types of data were analyzed: data on the infants’ attention for the stimuli (i.e. percentage of stimulus fixation, number of times turning away), data on the nature of the scanning movements (i.e. duration of fixations, number of fixations), and data on the location of the fixations while looking at the mother stimulus. The data on infants’ attention for the stimuli and the nature of the scanning movements were analyzed using 6 (age) x 2 (stimulus) repeated measures analyses of variance (ANOVAs). Data were missing for one session for one infant. Group means were used for this session. In several cases the correlation matrices between the different measurement points were heterogeneous. In these cases, the degrees of freedom of the $F$ test were corrected according to the Greenhouse-Geisser method.

The data on the locations of the fixations were incomplete for the reasons mentioned previously. The percentage of time for which information on fixation locations was available is shown in Table 2.1. From this data set, percentages of time spent fixating the different regions of the face were calculated for each session. The change in the duration of looking at different zones of the stimulus across ages was examined using a linear regression of the averages. To test the significance of differences between the duration of fixating the different face regions, a permutation method, a procedure linked to the group of bootstrap techniques, was implemented (for an introduction see e.g., Good, 1999; Efron & Tibshirani, 1993). Permutation methods make it possible to estimate the probability that the observed values of crucial test statistics (e.g., the difference between averages, the slope of a regression line, etc.) can be explained by the null hypothesis model without having to make assumptions about expected distributions across the “population” of observations (e.g., a normal distribution). Further, they are especially suitable for analyzing data from a longitudinal design as they allow for missing values. Resampling methods are becoming more and more common in the social sciences because of their diversity and flexibility (see e.g., van Geert & van Dijk, 2002; Boosman, van der Meulen, van Geert, & Jackson, 2002).
Table 2.1. Percentage of time for which information on the fixation location was available (presentation of the mother stimulus) by infant and age.

<table>
<thead>
<tr>
<th>Infant</th>
<th>6 weeks</th>
<th>10 weeks</th>
<th>14 weeks</th>
<th>18 weeks</th>
<th>22 weeks</th>
<th>26 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.00</td>
<td>69.0</td>
<td>0.00</td>
<td>80.7</td>
<td>92.8</td>
<td>84.8</td>
</tr>
<tr>
<td>2</td>
<td>0.00</td>
<td>42.8</td>
<td>52.1</td>
<td>0.00</td>
<td>50.0</td>
<td>95.3</td>
</tr>
<tr>
<td>3</td>
<td>0.00</td>
<td>57.6</td>
<td>0.00</td>
<td>83.0</td>
<td>84.2</td>
<td>100.0</td>
</tr>
<tr>
<td>4</td>
<td>39.7</td>
<td>87.9</td>
<td>57.1</td>
<td>100.0</td>
<td>31.7</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>81.8</td>
<td>65.6</td>
<td>100.0</td>
<td>2.2</td>
<td>4.8</td>
<td>79.2</td>
</tr>
<tr>
<td>6</td>
<td>0.00</td>
<td>49.8</td>
<td>73.4</td>
<td>100.0</td>
<td>39.8</td>
<td>86.9</td>
</tr>
<tr>
<td>7</td>
<td>0.00</td>
<td>96.1</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>93.7</td>
</tr>
<tr>
<td>8</td>
<td>12.4</td>
<td>0.00</td>
<td>0.00</td>
<td>49.6</td>
<td>18.2</td>
<td>94.4</td>
</tr>
<tr>
<td>9</td>
<td>95.5</td>
<td>100.0</td>
<td>10.1</td>
<td>98.9</td>
<td>51.3</td>
<td>81.4</td>
</tr>
<tr>
<td>10</td>
<td>0.00</td>
<td>95.6</td>
<td>89.3</td>
<td>100.0</td>
<td>79.9</td>
<td>97.2</td>
</tr>
</tbody>
</table>

Note. If there was less than 3 seconds of reliable measurement, the session was excluded from the analysis of location of fixation. Sessions excluded for this reason are marked.

RESULTS
There are two levels at which one can examine how infants look at a visual display (Bronson, 1994): At a higher level, it can be assessed how long the stimulus is looked at before attention is shifted away. The lower level is the dimension of single fixations. Here, the number and duration of each fixation is examined. In this study, infants’ attention for the two stimuli was examined first. Therefore, both the total time spent looking at the two stimuli and the number of gaze shifts away from the stimuli were analyzed. These measures provide information on infants’ attentiveness and interest for the two stimuli throughout the research period.

Percentage of Time of Stimulus Fixation
First, it was investigated how long the infants attended to and away from the stimuli. Therefore, the total duration of fixations on and off the stimulus (and subsequently the relative amount of time spent fixating on and off the stimuli) were calculated.

Effect of age. The percentage of time infants spent looking at the displayed stimuli changed significantly with age ($F(1.16, 10.45) = 4.89, p < .05$). The course of development of the average percentage of time spent fixating the two stimuli is shown in Figure 2.3. Pairwise comparisons with Bonferroni-correction revealed significant
differences between the first three and the last three measurement points, especially between the age of 10 (\(M = 91.6\%\), \(SD = 5.1\)) and 14 weeks (\(M = 88.9\%\), \(SD = 6.6\)) versus 22 (\(M = 72.4\%\), \(SD = 9.1\)) and 26 weeks (\(M = 71.6\%\), \(SD = 11.5\)). Because of the clear partition of the developmental course, the two parts (6 until 14 weeks and 18 until 26 weeks) were also analyzed separately. For the first three measurement occasions, the ANOVA demonstrated a significant effect of age (\(F(1.16, 10.45) = 4.74, p < .05\)) with a significant increase in looking time between 6 (\(M = 72.7\%\), \(SD = 24.0\)) and 10 weeks of age (\(M = 91.6\%\), \(SD = 5.1\)).

**Figure 2.3.** The averaged percentage of time spent fixating the mother and the abstract stimulus between 6 and 26 weeks of age (with standard errors).

**Effect of stimulus.** There was no main effect of the type of stimulus (abstract versus mother stimulus) and no significant interaction. If the two parts of the developmental course were analyzed separately, a significant Age x Stimulus interaction (\(F(1.31, 11.81) = 5.22, p < .05\)) was revealed, indicating that the increase in fixating time was greater for the abstract stimulus (6 weeks, \(M = 64.8\%\), \(SD = 30.7\); 10 weeks, \(M = 93.6\%\), \(SD = 4.8\)) than for the mother’s face (6 weeks, \(M = 80.6\%\), \(SD = 20.1\); 10 weeks, \(M = 89.7\%\), \(SD = 9.2\)). The second part of the developmental trajectory was characterized by stability: No significant effects of age or stimulus were found.

**Turning Away from the Stimulus Display**

**Effect of age.** The analysis of how often the infants turned away from the stimuli at the different ages (see Figure 2.4) revealed a significant effect of age (\(F(2.93, 26.39) =\)
15.67, \( p < .01 \)). Infants averted gaze from the stimulus more often as they grew older. Significant differences were found between the frequency of turning away at 6 (\( M = 2.0, SD = 1.3 \)) and 10 weeks (\( M = 1.6, SD = .9 \)) versus 18 (\( M = 5.3, SD = 2.4 \)), 22 (\( M = 7.0, SD = 1.8 \)) and 26 weeks of age (\( M = 6.6, SD = 2.9 \)).

Effect of stimulus. The analysis of how often infants averted their gaze yielded no significant difference between the two stimuli.

Figure 2.4. The averaged number of times of turning away from the mother and the abstract stimulus between 6 and 26 weeks of age (with standard errors).

Number of Fixations

To study the infants’ way of scanning the stimuli at the microlevel, the number and duration of fixations were examined. In addition, the distributions of fixation lengths were analyzed to assess the frequency of brief or prolonged fixations, as Bronson (1994) characterized them as typical for differently mature modes of scanning.

Effect of age. The development of the number of fixations while fixating on or off the stimuli between 6 and 26 weeks of age is shown in Figure 2.5. Although the overall time spent looking at the stimulus declined as the infants grew older, the number of fixations increased with age (\( F(5, 45) = 11.14, p < .01 \)). Pairwise comparisons with Bonferroni-correction demonstrated a significant increase in number of fixations between the age of 6 weeks (\( M = 14.3, SD = 4.9 \)) and 14 weeks (\( M = 25.0, SD = 6.1 \)) or older. The infants also fixated off the stimulus more often as they grew older (\( F(5, 45) = 10.11, p < .01 \)).
Effect of stimulus. The analysis revealed a significant effect of stimulus on the number of fixations ($F(1, 9) = 7.83, p < .05$). The mother’s face elicited significantly more fixations ($M = 26.4, SD = 4.3$) than the abstract stimulus ($M = 23.0, SD = 3.9$). T tests used as post-hoc tests revealed that the number of fixations on the stimulus was significantly larger if the stimulus was the mother’s face than if it was abstract at the age of 14 weeks (mother, $M = 29.2, SD = 7.9$; abstract, $M = 20.7, SD = 8.1$; $t(9) = 2.57, p < .05$) and 18 weeks (mother, $M = 32.0, SD = 7.9$; abstract, $M = 27.2, SD = 8.0$; $t(9) = 1.98, p < .10$). With respect to the number of fixations off the stimulus, the two types of stimuli did not differ significantly.

Figure 2.5. The mean numbers of fixations while fixating the mother and the abstract stimulus and while fixating away between 6 and 26 weeks of age (with standard errors).

Duration of Fixations

Effect of age. For each infant the median length of fixation was calculated per stimulus and session. The change in median fixation duration while fixating on or off the two stimuli over the measurement period is shown in Figure 2.6. The ANOVA revealed a significant decrease in median fixation duration while looking to the stimuli across the measurement period ($F(2.5, 22.52) = 4.44, p < .05$), from more than 1 s at 6 weeks (6 weeks, $M = 1.18$ s, $SD = .62$) to around .6 s at 18 weeks or older (18 weeks, $M = .68$ s, $SD = .23$; 22 weeks, $M = .64$ s, $SD = .10$; 26 weeks, $M = .60$ s, $SD = .07$). Concerning the fixations off the stimulus, there was also an almost significant decrease in duration as the infants grew older ($F(1.74, 15.65) = 3.43, p = .06$).
Developmental Changes in Visual Scanning

Effect of stimulus. From the age of 14 weeks on, there was a significant difference in median fixation length between the abstract stimulus and the mother stimulus \((F(1, 9) = 15.27, p < .01)\), with the abstract stimulus \((M = .78 \text{ s}, SD = .21)\) eliciting longer fixation durations than the mother \((M = .61 \text{ s}, SD = .12)\).

A repeated measures ANOVA \((6 \times 2; \text{Age x On/off})\) comparing the median duration of fixations on and off the stimulus revealed a significant effect \((F(1, 9) = 37.61, p < .01)\) due to longer fixations when regarding the stimuli versus looking away from the monitor. The fixation duration while fixating off the stimulus did not vary significantly as a function of the type of stimulus.

![Figure 2.6](image.png)

*Figure 2.6.* The averaged median fixation durations while looking at the mother and the abstract stimulus between 6 and 26 weeks of age (with standard errors).

Distributions of fixation durations. To gain a clearer picture of the change in length of fixations over the measurement period, the distributions of the fixation durations at the different ages were examined. As representative examples, the distributions at the age of 6, 14, and 26 weeks and the different stimuli are shown in Figure 2.7. The fixation lengths are distributed approximately around .5 s, with most of the fixations lasting between .2 and .9 s. However, this might not apply to the age of 26 weeks: Here there seem to be two distinct distributions for the mother and the abstract stimulus with two different modal values. As the distributions found in this study were broadly similar to those reported in Bronson (1990a), his criterion of labeling those fixations as “brief” that last .7 s or less was applied. The percentage of brief fixations increased as infants grew older, especially in the second half of the measurement period. At 6 and 14
Figure 2.7. The distributions of fixation durations while looking at the mother and the abstract stimulus at (A) 6 weeks, (B) 14 weeks, and (C) 26 weeks of age.
weeks of age, on average 42.8% \((SD = 13.4)\) and 46.6% \((SD = 15.3)\) of the infants’ fixations were brief, compared to 64.4% \((SD = 6.1)\) at 26 weeks. A paired-samples \(t\) test revealed a significant increase in the proportion of brief fixations between the third and the last measurement session \((t(9) = 4.09, p < .05)\). Whereas at 6 weeks the percentages of brief fixations for the two different stimuli did not differ (mother, \(M = 38.8\%, SD = 13.2\); abstract, \(M = 46.7\%, SD = 23.7\)), at 14 weeks and 26 weeks the abstract stimulus elicited an almost significantly smaller percentage of brief fixations than the mother’s face \((14 \text{ weeks}, t(9) = 2.44, p < .05; 26 \text{ weeks}, t(9) = 2.08, p = .067)\). During the abstract display, on average only 40.9% \((14 \text{ weeks}, SD = 16.6)\) and 59.0% \((26 \text{ weeks}, SD = 11.4)\) were brief, versus 52.4% \((14 \text{ weeks}, SD = 17.4)\) and 69.8% \((26 \text{ weeks}, SD = 8.9)\) while the infants were regarding their mothers.

To explore the incidence of extremely long fixations, the percentage of fixation lengths greater than 2.5 s were calculated for each infant per session and stimulus. Although very long fixations were frequently observed at 6 weeks \((M = 19.0\%, SD = 10.7)\), their occurrence decreased between 14 and 26 weeks of age \((14 \text{ weeks}, M = 11.4\%, SD = 7.7; 26 \text{ weeks}, M = 2.4\%, SD = 3.5; t(9) = 5.22, p < .01)\). Again, differences between the two stimuli were found. While the percentages of long fixations were about the same at 6 weeks (mother, \(M = 19.0\%, SD = 9.4\); abstract, \(M = 19.0\%, SD = 17.5)\) and 26 weeks (mother, \(M = 2.8\%, SD = 3.4\); abstract, \(M = 2.0\%, SD = 4.9\)), at 14 weeks the abstract stimulus elicited a higher percentage of very long fixations \((M = 16.0\%, SD = 13.7)\) than the video of the mother \((M = 6.9\%, SD = 4.3)\). A paired-samples \(t\) test demonstrated an almost significant difference \((t(9) = 2.16, p = .059)\).

**Location of Fixations**

To examine which regions of their mother’s face infants looked at throughout the measurement period, the durations of fixations assigned to the same face regions (see Figure 2.2) were added up, and proportions of time spent looking at the different regions of the face were calculated.

*Table 2.2. Percentages of time spent fixating the different regions of the face stimulus by age.*

<table>
<thead>
<tr>
<th>Region</th>
<th>6 weeks</th>
<th>10 weeks</th>
<th>14 weeks</th>
<th>18 weeks</th>
<th>22 weeks</th>
<th>26 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouth</td>
<td>39.98</td>
<td>48.17</td>
<td>44.88</td>
<td>50.38</td>
<td>51.54</td>
<td>57.19</td>
</tr>
<tr>
<td>Eyes</td>
<td>38.11</td>
<td>30.10</td>
<td>48.10</td>
<td>38.88</td>
<td>26.95</td>
<td>29.74</td>
</tr>
<tr>
<td>Edge</td>
<td>18.52</td>
<td>17.82</td>
<td>5.87</td>
<td>8.93</td>
<td>18.36</td>
<td>11.87</td>
</tr>
<tr>
<td>Body</td>
<td>0.00</td>
<td>2.32</td>
<td>0.22</td>
<td>0.00</td>
<td>0.40</td>
<td>0.00</td>
</tr>
<tr>
<td>Background</td>
<td>3.38</td>
<td>1.60</td>
<td>0.91</td>
<td>1.81</td>
<td>2.74</td>
<td>1.19</td>
</tr>
</tbody>
</table>
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The distribution of the percentages and its change over time is shown in Table 2.2. To test for a possible effect of age, a regression model was used. A linear effect of age was found only for the mouth region ($b = .11, t(8) = 6.99, p < .01$). The percentage of time spent looking at the mouth region increased significantly from 39.98% at 6 weeks to 57.19% at 26 weeks of age.

To test whether two percentages of fixation duration were significantly different from each other, a permutation technique was implemented.¹ From Table 2.2 it can be seen that the percentage of time spent fixating the edges of the face was smaller than the percentage of time spent fixating the mouth and the eye region throughout all measurement sessions. At 6 weeks of age, none of the differences was significant. This might be due to the very small amount of data available at the first measurement point (see Table 2.1). The difference between the time spent fixating the mouth and the edges reached statistical significance from the age of 10 weeks on (10 weeks, $p = .02$; 26 weeks, $p = .01$). The difference between the time spent fixating the eye region and the borders of the face was significant at 14, 16, and 26 weeks ($p = .02, p = .004, p = .01$, respectively). At 26 weeks, there was also an almost significant difference between the time spent fixating the mouth and the time spent fixating the eyes ($p = .08$) with more time being spent on the mouth. Percentages of time spent fixating other parts of the stimulus display (such as the mother’s body or the background) were negligible.

**DISCUSSION**

*Development of Attention for the Face and the Abstract Stimulus*

Initially, some results on infants’ attention for the two stimuli will be discussed to provide the background for the subsequent considerations on scanning patterns. The infants in this study showed considerable interest for the stimuli they were

¹ In this study, a Monte Carlo approach to the permutation method was applied. It uses the actual data to calculate the level of significance of parameters. Assume we want to test, whether the parameters M and E, each based on a set of observations in a group of participants, are significantly different from each other. Our hypothesis then states that the two parameters are different. That is, we can conceive of the set of observed values, which forms the basis of the first parameter M, that it is drawn from a different distribution (with different mean) than the observations that led to the calculation of the second parameter E. The null hypothesis, on the other hand, claims that the observed difference is coincidental and that the two sets of observations have been drawn from a single distribution. This means that the assignment of an observed value to either the first or the second set of observations would be purely random. We simulate this condition by randomly assigning a label of the first or second set to the values collected in the common set. If we carry out a large number of such random permutations (e.g., 10000), we obtain an approximation of the exact chance distribution of the difference between M and E. We can now determine the number of times that the simulated null hypothesis difference between M and E is as large as or larger than the observed difference between M and E. If the number of simulations is big enough, the proportion of this number over the number of simulations provides an estimation of the $p$ value of the observed difference, that is, the probability that the observed difference has been the result of the null hypothesis model.
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presented with. During the first measurement session, infants spent on average about three quarters of the time looking at the stimuli. The time spent regarding the dynamic stimuli followed a course of development well-known from earlier studies (see Colombo, 2002): The infants’ attention increased between 6 and 10 weeks of age, reaching its maximum when infants were 10 to 14 weeks old, before decreasing again between 18 and 22 weeks and subsequently stabilizing at the 6-week level. However, although infants spent about the same time looking away from the stimulus when they were 6 weeks old as when they were 5 months and older, there was an important difference in looking behavior at the two ages. At the younger ages, fixations were longer and infants looked away from (and back to) the stimulus less often, which is consistent with the poor gaze shifting control often observed in infants of this age (Aslin & Salapatek, 1975; Hood & Atkinson, 1993). The finding that at 6 weeks infants nevertheless spent more time attending to their mother’s face suggests that within these general limitations they might be able to preferentially direct their attention to a face (see Morton & Johnson, 1991).

From the age of 18 weeks on, infants exhibited a different pattern of regarding. They tended to alternate short fixations of the stimuli with short looks away. This pattern has been observed frequently from 3 months of age on, both during social interaction and during inspection of inanimate stimuli. Babies start shifting their gaze between their partner and the surroundings at this age (Kaye & Fogel, 1980; van Wulfften Palthe, 1986). Such gaze shifting might have a regulatory function both in the social context (Stifter & Moyer, 1991) and during inspections of inanimate stimuli when infants regulate the flow of visual input to enable efficient information processing (Colombo, 1993).

Development of Scanning of the Face and the Abstract Stimulus

There are some remarkable changes taking place in the way infants scan the two dynamic stimuli in our study. The number of fixations increased significantly during the measurement period, while the fixation length decreased. This is in accord with previous research (Bronson, 1994, 1996). The number of fixations increased most rapidly between 6 and 18 weeks of age; the median fixation duration declined most strongly between 10 and 18 weeks of age. Only after 18 weeks did neither parameter change significantly. A stable scanning pattern thus emerged a little later than in the studies of Bronson (1990a, 1994), who concluded that infants’ scanning of static stimuli was similar to that of adults around 14 weeks of age. From 14 weeks on, a stable difference in median fixation length when looking at the abstract or the face stimulus was found.

When the results on number and duration of fixations are considered together with the changes over age in the distributions of fixation durations for each stimulus, three important points come forward. First, the median fixation duration did not become stable until 18 weeks of age, and at 14 weeks scanning behavior was still characterized
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by more staring behavior and fewer brief fixations than at the end of the measurement period. We attribute this effect to the dynamic nature of both stimuli and their increased sensory salience prolonging the occurrence of subcortically controlled scanning patterns, which are usually found in younger infants. This is also supported by the finding that infants exhibited much shorter average fixation durations when fixating off the stimulus display. These results are consistent with earlier findings of Johnson and Johnson (2000), who also reported a protracted developmental course for infants’ scanning of complex, moving stimuli. Taken together, these findings suggest that the development of scanning of more demanding stimuli is extended compared to relatively simple, achromatic stimuli.

Second, the persistence of less advanced scanning behavior at 14 weeks was especially marked when the infants were examining the abstract stimulus. This is suggested by the higher proportion of extremely long fixations for the abstract compared to the mother stimulus found at 14 weeks but not at 6 and 26 weeks of age. To explain this effect, one has to take into account that there might have been a discrepancy in salience also between the abstract and the face stimulus. Although they were comparable in terms of dynamics, color range, and luminance, the abstract stimulus contained more plain areas of the same color and thus more contrast and less clear structure. Its movements and its change of structure were less predictable. As a consequence, the less advanced scanning behavior might have been more prominent when infants were inspecting the abstract stimulus than their mother’s face. This suggests that before mature scanning patterns have become well established, scanning behavior may be particularly susceptible to the characteristics of a stimulus.

Third, a stable difference between the median fixation durations of the two stimuli was found from 14 weeks on, which is also reflected in the difference in the percentage of brief fixations during the scanning of the two stimuli at both 14 and 26 weeks of age. This effect indicates the existence of two distinct, rather narrowly confined distributions of short fixation durations as they are depicted in Figure 2.7 B and C. Infants of 14 weeks and older have considerable experience in scanning faces. Moreover, their mother’s face is very well-known to them by this time (Barrera & Maurer, 1981). The abstract display, on the other hand, might still have been novel. It was highly salient, moved in an unpredictable way, and did not have the clearly defined structure of meaningful elements found in a face. As it is the function of short fixations to provide the visual system regularly with new input, a scanning pattern with slightly longer fixation durations may have been well adapted and highly functional to examine the abstract stimulus. Thus, one important conclusion from our findings is that infants adjusted their way of scanning to the characteristics of the different stimuli from the age of 14 weeks on.

Compared to some earlier research on infant scanning patterns (e.g., Harris & Hainline, 1987), the median fixation durations found in this study seem to be rather long. On the one hand, one can attribute this finding partly to differences between
the characteristics of the stimuli used in the different studies (e.g., complexity, dynamic aspects, or salience). On the other hand, these differences can also be due to the methods of processing the raw eye position data as Bronson (1990a) already pointed out. One has to keep in mind that it is of limited value to compare parameters from different studies, as their range depends crucially on how they are derived from the actual eye position data and how a fixation and an eye movement are defined. In this study, the criterion used permitted very small drifting movements or extremely slow eye shifts within a fixation interval because of the dynamic properties of the stimuli. Under these circumstances, it is especially important to concentrate on differences of parameters across different stimuli and ages within the same study.

**Development of Location of Fixations on the Mother’s Face**

When infants were scanning their mother’s naturally moving face, they looked mainly at her mouth and eyes. The borders of the face did attract some attention, especially at the ages of 6 and 10 weeks, but – at least from 10 weeks on – the inner elements of the face were significantly more interesting to the baby. Even at the youngest age, no indication of an edge preference was found. As mentioned before, previous studies demonstrated strong effects of edge attraction in young infants who were regarding static or moving but less natural representations of faces. This study raises doubts about whether this also holds for natural interaction situations. It is possible that the intense, exaggerated, and slowly paced facial movements characteristic of mother-infant interactions (Stern, 1974) were a more powerful attractor of the infant’s attention than the contours outlining the face. However, a final conclusion concerning this question is not possible because the number of successful measurements with the 6-week-olds was limited. Edge preference has been shown to influence the infant’s visual behavior most strongly around 1 month of age, making it likely that any possible effect might have been only mildly present in the 6-week-olds tested for this study. Further research thus is indicated here.

From the first test session on, the mother’s mouth drew much attention. The time infants spent fixating the mouth region increased significantly throughout the measurement period, which might indicate their growing interest in language. This finding contrasts with the results of earlier studies, which reported the mouth to be a less (or even the least) regarded area (Maurer & Salapatek, 1976), even when the stimulus was a talking face (Haith et al., 1977). One explanation is that the mothers were performing the facial activities of a natural interaction (such as smiling or slowly articulating relatively simple words), which were particularly attractive and suitable for babies. However, the stimulus videos in this study were displayed silently. The effect thus might also reflect the infants’ growing astonishment to see a moving mouth without hearing the matching sound.

Concerning the reaction to faces, our results indicate a clear advance between 10 and 14 weeks of age. The distribution of durations suggested the overcoming of sticky
fixation while scanning the face stimulus, and concurrently, the proportion of time spent fixating the edges of the face reached its lowest point. Thus, the infants started scanning the face routinely and paid more attention to the particularly meaningful regions of a face: the eyes and the mouth. This transition seems to go together with changes in mother-infant interaction. After about 12 weeks of age, the infant takes an increasingly active part in en face interaction (van Wulfften Palthe, 1986).

REFERENCES
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