Chapter 3

Gaze Shifting in Infancy: A Longitudinal Study Using Dynamic Faces and Abstract Stimuli

Abstract
Disengaging from and shifting gaze to a salient stimulus is a prerequisite for early exploration and communication. The efficiency of disengagement increases during the first few months after birth. Little is known about the effect of stimulus characteristics on disengagement during the different stages of its development. Twenty infants were studied longitudinally between 6 and 26 weeks of age. The frequency and latency of gaze shifts to peripheral targets were measured in a competition and a non-competition situation. The stimuli were a short video of the baby’s mother’s face and an abstract video, both appearing as central stimulus or peripheral target. In the competition condition, infants were more likely to shift their gaze when the central stimulus was a face and the peripheral target was abstract. They moved their gaze least frequently and with greater latency in the opposite condition (abstract-face). Disengagement developed rapidly between 6 and 22 weeks of age. Differences between stimulus combinations were most marked between 10 and 18 weeks.

INTRODUCTION

Optimal development depends largely on learning about objects and people in the surrounding world. This is especially true for infants. From birth on, they explore their environment visually. Effective visual exploration requires shifting gaze across different locations. Adults are very skilled in quick visual search and scanning. Infants, on the other hand, may show long periods of staring. This study addresses the question of how shifts of attention and gaze develop through infancy and whether this developmental trajectory is dependent on characteristics of the stimuli involved.

The Development of Attention Shifting

The attentional skills which support the visual exploration of the environment develop during the first months of life. Babies between approximately 1 and 3 months of age have been reported to spend long periods staring and to have difficulty disengaging from an object or stimulus they are attending to (Hopkins & van Wulfoten Palth, 1985). Stechler and Latz (1966) named this behavior “obligatory attention”, others noticed that infants seemed “stimulus-bound” or “overwhelmed” (Tennes, Emde, Kisley, & Metcalf, 1972, p. 218) or “glued to the pattern” they were examining (Cohen, 1976, p. 235). This effect of a stimulus in central vision impeding the shifting of attention to a second, competing stimulus in the periphery has been demonstrated frequently (e.g., Harris & MacFarlane, 1974; Aslin & Salapatek, 1975; Mohn & van Hof-van Duin, 1986). The phenomenon of obligatory attention seems to be strongest in infants of 1 and 2 months. The frequency and speed of shifts of gaze to a target in the periphery with a stimulus persisting in the center increase substantially around 3 to 4 months of age (Hood & Atkinson, 1990; Johnson, Posner, & Rothbart, 1991; Butcher, Kalverboer, & Geuze, 2000). Saccadic reaction times in situations with competing stimuli tend to be longer than in non-competition situations where no disengagement of attention or gaze has to take place prior to the execution of an eye movement (Atkinson, Hood, Wattam-Bell, & Braddick, 1992). This effect has been shown to be largest in infants younger than 3 months (Matsuzawa & Shimojo, 1997), but has also been demonstrated in older infants and in adults (Hood & Atkinson, 1993).

Unraveling Attention Shifts in Infancy

The phenomenon of obligatory attention is not yet completely understood. Richards (1997) suggested that it is not caused by a decrease in peripheral sensitivity, but rather by an increased bias against responding when attention is engaged on the focal visual stimulus. Different explanations for this disengagement difficulty have been proposed. Hood (1995) coined the term “sticky fixation” for the phenomenon emphasizing infants’ difficulty in breaking gaze from a stimulus they are fixating. According to Johnson (1990), obligatory attention can be attributed to the inability to produce an orienting eye movement to a peripheral target while processing the stimulus in the central visual field. Rothbart, Posner, and Rosicky (1994), however, suggested that shifts of gaze are
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preceded by covert shifts of attention and that disengagement problems reflect difficulty orienting covertly to the periphery. Within all three accounts, disengagement problems can be described in terms of two processes competing with each other: a tendency to maintain the focus of attention and gaze, and a tendency to shift attention and gaze to a new location. Accordingly, disengagement difficulty is explained by the relative maturational state of the collicular and cortical areas which subserve these mechanisms (Johnson, 1990; Hood, 1995; Rothbart et al., 1994).

Earlier research has shown that the characteristics of the stimuli used in an attention shifting task influence the reaction of the baby. Non-competition experiments, in which a focal stimulus was replaced by a peripheral target, have found that the size (Cohen, 1972) and the form (Maurer & Lewis, 1979) of the peripheral stimulus affect the probability and latency of localization, while speed of stimulus movement does not (Finlay & Ivinskis, 1982, 1984).

Stimulus attributes also seem to play a role when two stimuli are presented at the same time. Finlay and Ivinskis (1984) demonstrated that a comparatively salient stimulus in the central field makes it more difficult for infants to disengage their gaze. There are also indications that the effect of a salient central stimulus might change with age, being strongest between 9 and 16 weeks (Butcher et al., 2000). Tronick (1972) found that the frequency of detection of a target further in the periphery increased between 2 and 10 weeks of age when the central stimulus was static and the target was moving, but not when the central stimulus was moving and the target was static.

Shifts of gaze seem to be a function not only of what is currently being attended to in the central visual field, but also of what is competing for attention in the periphery. Finlay and Ivinskis (1984) demonstrated that infants of 4 months detected and processed information about stimuli in the periphery even when their gaze did not shift from a central stimulus they had been fixating first. In another disengagement experiment, Matsuzawa and Shimojo (1997) found much shorter gaze shifting latencies than Hood and Atkinson (1993) had found before in a similar cross-sectional study with 1.5- to 6-month-olds and attributed this to the fact that they had made use of a less attractive central fixation stimulus and a more attractive target. However, Hicks and Richards (1998) did not find an effect of a dynamic versus a static peripheral stimulus on frequency and latency of gaze shifts between 2 and 6 months of age.

To summarize, the current results concerning the role of stimulus characteristics in shifts of attention are both incomplete and inconsistent. It has not yet been precisely investigated how variation in the characteristics of the central and the peripheral stimulus influences shifts of attention and how this changes throughout infancy.

Disengagement and Social-Emotional Development

Vision is crucial not only for exploring and learning about the environment but also during social interaction. During face-to-face interaction with their mother or another caretaker, infants from the age of 3 months on often shift their gaze away from...
and back to the other person’s face. These periods of looking away from the mother’s face occur both in situations with negative emotionality (Cohn & Tronick, 1983) and during pleasurable interactions (Stifter & Moyer, 1991). As infants grow older, the attention they pay to their mother’s face during social interaction declines, and they start fixating other locations more often (Kaye & Fogel, 1980; van Wulfften Palthe, 1986). Johnson and co-workers interpret this shift as a sign of basic changes in the child’s ability to disengage attention and gaze from a location and to anticipate events that are going to occur at other spatial locations (Johnson et al., 1991).

The distress that has been described as accompanying obligatory attention (Stechler & Latz, 1966; Tennes et al., 1972) suggests that attention and emotion are closely linked. Furthermore, it is a daily observation that a mother can relieve her infant’s unhappiness by letting him or her orient to something new (e.g., a toy). In accordance with this, it could be shown that babies of 4 months of age who have higher abilities in disengaging from a visual stimulus are more soothable and less susceptible to distress (Johnson et al., 1991). The attention system thus forms a basis for self-regulation already in early infancy (Posner & Rothbart, 1981).

Taking into account the functional importance of attentional behavior and gaze shifting discussed earlier, it is surprising that there have been relatively few attempts to study the development of gaze shifting and the underlying attentional processes in functional contexts, for example, by using different and more socially relevant stimuli.

**Aims of the Study**

The goal of this study was to explore how the nature of the stimuli used affects gaze and attention shifting behavior in infancy. Both abstract and meaningful stimuli were used. Human faces are among the most important stimuli in the visual world of infants. They also play an important role in their social-emotional development. We therefore chose the infant’s mother’s face as it moved in a natural way as social stimulus and a stimulus with similar physical characteristics as abstract stimulus. Since there is some – albeit inconsistent – evidence that the impact of the stimulus characteristics changes with age, the study focused on infants between 6 and 26 weeks of age, the period in which fundamental gaze and attention shifting mechanisms develop.

The aim was to study shifts of gaze both in a non-competition situation when the central and the peripheral stimulus were presented successively and in a competition situation when the central stimulus persisted after the peripheral stimulus appeared. In order to examine the influence of stimulus characteristics on both attention holding and attention getting, the two stimuli were used as central fixation stimulus and peripheral target. The effects of the different stimulus combinations were measured in terms of differences in the frequency and latency of peripheral target localization. We expected no distinct effect on gaze shifting in the non-competition condition, as the two stimuli should be equally easy to detect due to their similar physical charac-
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teristics. In the competition condition, we expected the characteristics of the stimuli to influence attention holding and attention attraction processes, leading to differences in the frequency and latency of gaze shifts. Around 5 or 6 months of age, we expected reliable disengagement to occur in all stimulus conditions. A possible effect of stimulus characteristics should then still be detectable in differences in the latencies of gaze shifts to the peripheral target. As earlier research has shown that the timing of attentional development may differ substantially between infants (Butcher et al., 2000; Finlay & Ivinskis, 1984), it was also investigated whether there were significant inter-individual differences in the development of gaze and attention shifting, possibly as a function of the influence of stimulus characteristics.

**METHOD**

**Participants**

Twenty infants (12 girls; 8 boys) took part in the longitudinal study. Their mothers were approached through childbirth education classes, midwives, or gym classes. To be admitted to the study, infants had to meet a set of criteria: a gestation period of 37 to 42 weeks, a birth weight above 2800 g, and no history of pre- and 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. Parents were informed about the purpose of the study and gave their informed written consent. The research was approved by the local Medical Ethics Committee.

The measurements started when the infants were about 6 weeks old and continued every 4 weeks until they were 26 weeks old. Ages were calculated from the due date. If the infants were unable to carry out the experimental task due to fussing or sleepiness, a new appointment was made within 7 days. Despite attempts to retest, one of the measurement sessions was missing for 7 infants. Mean ages at each measurement session were 47.7 days ($SD = 4.1$), 73.6 days ($SD = 4.7$), 103.7 days ($SD = 4.0$), 131.1 days ($SD = 3.2$), 158.9 days ($SD = 3.4$), and 188.8 days ($SD = 4.8$).

**Procedure**

Measurement sessions were scheduled for a time when parents expected their baby to be alert for 20 to 30 minutes. After arriving at the lab, infants were given some time to become used to the new environment. When they were 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.

The infants carried out a so-called disengagement task. In such a task stimuli can appear at three different positions on a screen: in the center, on the left, or on the right. The stimuli to the left or right were presented at 20 degrees eccentricity. The disengagement task included two different sorts of trials: competition and non-competition trials. All trials started with the display of a stimulus in the center of the monitor, the fixation stimulus. To attract the attention of the infant, the onset of this
stimulus was accompanied by a short melody. After the infant had been fixating the central stimulus for 1 - 2 seconds, the peripheral stimulus appeared. In competition trials, the first stimulus persisted after the peripheral target appeared; in non-competition trials, it disappeared when the peripheral stimulus appeared. After 5 seconds, the stimuli disappeared simultaneously. The screen remained blank for 2.5 seconds, before the following trial began.

Figure 3.1. Schematic representation of a disengagement task with (A) a competition and (B) a non-competition trial.
Figure 3.1 shows a schematic representation of the disengagement task with (A) the competition condition and (B) the non-competition condition. Competition trials thus required disengagement of attention and gaze from the fixated central stimulus before an eye movement to the peripheral target could be carried out. Non-competition trials did not require disengagement.

**Apparatus**

The babies carried out the task while sitting in an infant-seat on a table in a reclined posture (about 45 degrees) with a light support of their head. The infant-seat was located in front of a 21 inch monitor, which was suspended from the ceiling approximately central and perpendicular to the line of gaze. The distance between the monitor screen and the baby’s eyes was about 35 cm. Only the screen of the monitor was visible to the infant. The monitor itself, the equipment necessary to run the tasks and record eye movements, and the experimenter were hidden behind a gray curtain, which filled 180 degrees of the baby’s visual field. During the experiment, the infant’s face and eye movements were videotaped. The eye movements and the display of the monitor were also shown on a video monitor, allowing the experimenter to run the task on the basis of the infant’s behavior. The babies’ eye movements were scored offline from the video recording.

**Stimulus Material and Stimulus Presentation**

Two different dynamic stimuli were used within the disengagement task: an abstract stimulus and a meaningful stimulus. Both stimuli were in color. The meaningful stimulus consisted of a short video sequence of the face of the infant’s mother. This video recording was made during a first visit of mother and baby to the lab. The mother’s face was recorded while she was smiling and talking with her baby as she normally would do. The abstract stimulus was then derived from the video of the mother by carrying out several transformations in a graphic computer program (Corel PHOTO-PAINT 9). During the transformation the image of the mother was rotated, scrambled, and distorted. This frame-by-frame procedure ensured that the two stimuli resembled each other regarding their dynamic characteristics, color range, and luminance, but were completely different with respect to their meaning to the infant. One frame from each type of video is given as a stimulus example in Figure 2.1 (see Chapter 2).

At the viewing distance of 35 cm, all stimuli subtended a visual angle of 10 by 10 degrees. Thus, the face was much smaller than it would appear to the baby in a normal interaction. As even newborns can recognize a well-known face after a size change (Walton, Armstrong, & Bower, 1997), we expected that the infants would not have any problems with the size of the face. This was supported by observations during the experiment, which showed the infants’ interest for the stimuli and their smiling to the mother stimulus but not to the abstract stimulus.

The experiment contained 32 competition trials and 8 non-competition trials. As
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reactions to the peripheral stimulus in the non-competition condition were expected to be less variable, fewer non-competition trials were considered to be necessary to provide reliable measurements. Both stimulus types could appear as central stimulus or as peripheral target. The different combinations of the two stimulus sorts (face-face, face-abstract, abstract-face, abstract-abstract) were presented with equal frequency. Half of the peripheral targets appeared on the left, half on the right side. The order in which the trials were presented was randomized. An experimental run normally lasted about 12 minutes. Whenever the infant started fussing or crying or became sleepy, the testing session was interrupted for some time.

Analysis

Behavioral coding. The eye movements on the video recordings of the infant's face were coded off-line from the tape, which was played back half-frame by half-frame (20 ms intervals). The direction and latency of the first eye movement after the peripheral stimulus appeared were scored. Trials in which the infant was not fixating the first stimulus when the peripheral stimulus appeared were excluded from the analysis. This could be trials in which, for example, the infants had already averted their gaze from the central stimulus or had their eyes closed for various reasons (e.g., blinking, yawning, fussing). Eye movements starting less than 200 ms after the second stimulus appeared, were considered anticipatory (Haith, Hazan, & Goodman, 1988) and also dropped from the analyses.

All eye movements following the appearance of the peripheral stimulus but not leading to its localization were considered to be errors. Different sorts of errors were distinguished: errors in which the infant looked up or down instead of to the periphery, carried out a horizontal eye movement in the opposite direction of the target, or looked in the direction of the target but went beyond it or did not reach it. If the peripheral target was localized by means of multiple successive saccades, this was scored using a separate code, but counted as a successful shift of gaze, as long as the gaze did not miss the target.

The data were coded by different observers, who had been trained by the first author. About 10% of the sessions were double-coded. Interobserver reliability for the onset of an eye movement was found to be on average 93.5% (range 89.5% to 100%). Cohen's kappa for the category of first eye movement was on average .82 (range .72 to 1.0).

Statistical analysis. The relative frequency of looks to the peripheral target as well as the frequency and type of error were calculated for each test session and condition. To calculate the latencies of looks, the time differences between the appearance of the peripheral stimulus and the onset of an eye movement to this target were calculated. Then, the median reaction times for each infant, session, and stimulus combination were determined. As a plot of all median reaction times revealed, the distribution of the raw data was positively skewed, and therefore a square root transformation was
carried out (Rummel, 1970) before carrying out the statistical analyses. For ease of understanding, the averaged response latencies reported in the text and the reaction times depicted in the figures are given in seconds.

The data were analyzed using a multilevel modeling technique (Snijders & Bosker, 1999; Woodhouse, 1996). Multilevel analysis is a regression procedure which takes into account a possible hierarchical structure of the data set. When applied to longitudinal data, the repeated measures are regarded as “nested” within individuals. Unlike a standard multiple regression model, a multilevel model contains more than one error term: one for every level of the hierarchical data. The model also allows intercept and slope coefficients to vary randomly, which means that the association between session scores and explanatory variables may differ between individuals. Another strength of this approach is that it allows for both the number of observations per individual and the spacing of the observations in time to vary.

Multilevel analysis was used to examine whether (a) the frequency and latency of looks and the frequency of errors changed with age, (b) the combination of stimuli influenced the frequency and latency of looks, and (c) the data was described best by a model which allowed for inter-infant differences. The data of the competition and the non-competition trials were analyzed separately and treated as different subsets of data. The models had three levels: infant, test session, and stimulus combination. Based on earlier research (e.g., Butcher et al., 2000), a model of three piecewise linear functions was fit to the data. Previous studies suggested rapid development for the period from 6 to 9 and from 9 to 16 weeks and a stabilization for the period between 16 and 26 weeks of age. As looks to the competing target were very infrequent at 6 weeks, reliable latency data were not available for the first measurement point. A model of two piecewise linear functions was therefore used for the reaction time data, with one function from 9 to 16 weeks and another from 16 to 26 weeks. Infants’ test sessions differed concerning the number of trials carried out. This was controlled for by including a correction term into the models. As the infants’ real ages were entered into the model rather than age categories, the variable age could be treated as a continuous variable, which provided information on infants’ performance also between the measurement points.

For the analyses, the data was centered around 12 weeks of age, which was about the middle of the period in which the largest change was expected. The parameters for the different age periods and the different stimulus combinations were added to the equation in order to predict the frequency of looks or the reaction times. T tests were used to determine the statistical significance of the coefficients. The fit of the model and its improvement was examined using \( \chi^2 \) tests of deviance. Whenever multiple T tests were carried out (e.g., as post-hoc tests), Bonferroni corrections were implemented to keep alpha at .05 (Stevens, 1992).
RESULTS

Frequency of Shifts of Gaze to the Peripheral Stimulus

Non-competition trials. The overall percentage of shifts of gaze to the periphery increased from 66.0% (SD = 40.8) at 6 weeks to 90.7% (SD = 18.8) at 10 weeks (see Figure 3.2). After the age of 10 weeks, there were no significant changes. This was indicated by the variable age having a significant coefficient for the 6 to 9 week function ($t(106)= 3.98, p < .001$), but not for the 9 to 16 week function and the 16 to 26 week function.

The frequency of looks to the peripheral stimulus in the non-competition condition per stimulus combination is shown in Figure 3.3. No significant effect of stimulus combination was found in any age period. There were no interaction effects of time and stimulus combination. As can be seen from the standard error bars in Figure 3.3, inter-infant differences were rather large. There was also a significant effect for the estimate of the slope variance for the 6 to 9 week function ($\chi^2(1) = 4.54, p < .05$) which indicates that infants differed in the rate at which gaze shifts increased during this period. However, it has to be kept in mind that in every test session there were only 2 non-competition trials per stimulus combination. The possible percentage of looks thus could be 0%, 50%, or 100%, which led to the large standard errors and the seemingly large inter-infant variance.

Figure 3.2. The mean frequencies and standard errors of looks to the peripheral target in competition and non-competition trials, and the mean frequency and standard error of errors in competition trials between 6 and 26 weeks of age.
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Figure 3.3. The mean frequency and standard error of looks in non-competition trials per stimulus combination between 6 and 26 weeks of age.

Competition trials. The overall frequencies of looks to the peripheral stimulus on competition trials across ages are depicted in Figure 3.2. Between 6 and 14 weeks of age, the frequencies were significantly lower than in the non-competition condition (6 weeks, $t(12) = -7.66, p < .01$; 10 weeks, $t(19) = -12.41, p < .01$; 14 weeks, $t(19) = -6.42, p < .01$). At 6 weeks, the frequency of looks was only 7.4% ($SD = 10.1$). It increased significantly throughout the measurement period to 29.9% ($SD = 25.0$) at 10 weeks, 73.8% ($SD = 25.7$) at 18 weeks, 88.0% ($SD = 12.6$) at 22 weeks, and 86.8% ($SD = 16.8$) at 26 weeks. The model accordingly contained almost significant coefficients of age for the 6 to 9 week function ($t(107) = 1.73, p < .10$), the 9 to 16 week function ($t(107) = 10.56, p < .001$), and the 16 to 26 week function ($t(107) = 4.17, p < .001$). However, the coefficient of age for the 9 to 16 week function was significantly larger than the one of the 16 to 26 week function ($\beta_{9-16} = 1.16$ versus $\beta_{16-26} = .27$). This was indicated by the significant gain in fit which was obtained by using separate coefficients of age for the periods of 9 to 16 and 16 to 26 weeks compared to only one age coefficient for the period of 9 to 26 weeks ($\chi^2(1) = 31.20, p < .001$). Consistent with this, comparisons of mean group frequencies of looks in consecutive sessions of the last age period yielded a significant effect only for 18 and 22 weeks ($t(14) = 3.58, p < .01$), while between 22 and 26 weeks of age there was no significant increase demonstrable anymore ($t(16) = -.86, p > .10$).

The proportion of looks to the peripheral target consisting of two or more saccades was large when infants were young (e.g., 6 weeks, $M = 27.0\%, SD = 1.9$; 14 weeks, $M = \ldots$
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29.6%, SD = 4.0) and decreased significantly between 14 and 26 weeks of age (26 weeks, M = 5.4%, SD = 1.6; t(19) = 3.39, p < .01).

As can be seen from Figure 3.4, the developmental trajectories for the different stimulus combinations diverge. The effect of the different stimulus combinations was tested by adding three of the four possible combinations as a 0-1 dummy variable to the model and contrasting them against the fourth category, the combination face-face. The main effects of the stimulus combinations face-abstract and abstract-face were significant. When controlling for age, the combination face-abstract elicited more frequent shifts of gaze than the reference category face-face (β\_face-abstract = 13.69; t(427) = 4.64, p < .001). With the combination abstract-face, on the other hand, gaze shifts occurred less frequently than in the reference condition (β\_abstract-face = -8.74; t(427) = -3.74, p < .001). Also with the stimulus combination abstract-abstract as reference category, there were significant effects of the combinations face-abstract (t(427) = 4.61, p < .001) and abstract-face (t(427) = -3.77, p < .001). There was no significant difference between the stimulus combinations face-face and abstract-abstract.

![Figure 3.4. The mean frequency and standard error of looks in competition trials per stimulus combination between 6 and 26 weeks of age.](image)

Three significant interaction effects showed that the frequency of shifts of gaze under the different stimulus conditions was associated with age (see Figure 3.4). In the age period between 6 and 9 weeks, the interactions between the stimulus combination abstract-face and age (t(427) = -2.57, p < .05) and face-abstract and age (t(427) = 1.83, p < .10) became almost significant. This indicates that, for this age period, the increase in
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disengagement frequency was smaller in the abstract-face condition and greater in the face-abstract condition. While the frequency of looks to the peripheral stimulus between 6 and 10 weeks increased from 9.8% \((SD = 21.5)\) to 44.5% \((SD = 25.1)\) in the face-abstract condition, with an abstract stimulus in the center and a face in the periphery it changed from 9.2% \((SD = 16.5)\) to only 18.3% \((SD = 16.0)\) in the same period of time. The third significant interaction effect was an interaction between the stimulus combination face-abstract and age \((t(427) = -3.17, p < .01)\) for the 16 to 26 week period. In the last age period the increase in the frequency of gaze shifting was smaller for the face-abstract stimulus combination than it was for the combination face-face. As Figure 3.4 also shows, unlike under the other three conditions, the frequency of gaze shifting in the face-abstract condition had almost reached its maximum at 18 weeks and did not increase substantially anymore (18 weeks, \(M = 85.1\%\), \(SD = 18.2\); 22 weeks, \(M = 90.2\%\), \(SD = 19.7\); 26 weeks, \(M = 88.8\%\), \(SD = 17.3\)).

In the analysis of random effects, the estimate of intercept variance was significant \((\chi^2(1) = 8.12, p < .01)\). This indicates that the frequency of looks differed significantly across infants at 12 weeks of age, which has been set as the intercept of the model. The slope variance for the age function 16 to 26 weeks turned out to be nearly significant \((\chi^2(1) = 3.83, p < .10)\).

Latency of Shifts of Gaze

Non-competition trials. In Figure 3.5, the development of the averaged median reaction times when shifting gaze to the periphery is depicted for the different stimulus combinations. The median reaction time declined from .58 s \((SD = .15)\) at 10 weeks to .41 s \((SD = .09)\) at 14 and .39 s \((SD = .07)\) at 22 weeks. In the multilevel model, the coefficient of the variable age was significant for the two age periods, 9 to 16 weeks \((t(102) = -7.16, p < .001)\) and 16 to 26 weeks \((t(102) = 2.06, p < .05)\). The age coefficients of the period 9 to 16 weeks \((\beta_{9-16} = -.0064)\) and 16 to 26 weeks \((\beta_{16-26} = .0008; \chi^2(1) = 47.71, p < .001)\) were significantly different from each other. The fact that the 16 to 26 week age coefficient was positive and significantly smaller than the coefficient of the age period 9 to 16 weeks suggests that the decrease in gaze shifting latency came to a standstill as infants grew older. Comparisons of averaged median reaction times in consecutive sessions revealed significant decreases only between 10 and 14 weeks \((t(18) = 5.56, p < .01)\), but not after 14 weeks of age, which also indicates a stabilization at the end of the measurement period.

There was no significant effect of stimulus combination. The slope variance estimate for the age period 9 to 16 weeks reached significance \((\chi^2(1) = 17.94, p < .001)\), indicating significant inter-infant differences in the rate of decrease of gaze shifting latency during this age period. Also, the estimate of the intercept variance was significant \((\chi^2(1) = 18.14, p < .001)\), which suggests that infants differed in their gaze shifting latency at 12 weeks of age.
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*Competition trials.* Until 22 weeks of age, the mean latencies to look to the peripheral target were significantly higher in the competition than in the non-competition condition (10 weeks, \(t(17) = 6.60, p < .01\); 14 weeks, \(t(19) = 4.96, p < .01\); 18 weeks, \(t(17) = 4.79, p < .01\); 22 weeks, \(t(16) = 3.19, p < .05\)). The development of the averaged median latencies of looks for the different stimulus combinations of the competition trials are presented in Figure 3.6. The mean latency of looks in the competition trials decreased from 1.42 s (SD = .62) at 10 weeks to .87 s (SD = .53) at 14 and .49 s (SD = .18) at 26 weeks. Both declines were significant (9 to 16 week age period, \(t(90) = -7.08, p < .001\); 16 to 26 week age period, \(t(90) = -2.83, p < .01\)). Coefficients of the two age periods differed significantly (\(\beta_{9-16} = -.0085, \beta_{16-26} = -.0017; \chi^2(1) = 22.59, p < .001\)), which suggests that the decline during the first part of the measurement period was larger than during the second part. *T* tests comparing the mean latencies of consecutive sessions accordingly yielded a significant decrease only between 10 and 14 weeks of age \((t(17) = 3.50, p < .05)\) and a trend between 18 and 22 weeks \((t(14) = 2.64, p < .10)\).

![Figure 3.5](image_url)  
*Figure 3.5.* The mean latency of looks and its standard error in non-competition trials per stimulus combination between 6 and 26 weeks of age.

The analysis also revealed an effect of stimulus combination. The main effect of the combination abstract-face indicates that – when controlling for age – the latency to shift gaze was longer than under the reference combination face-face \((t(346) = 2.74, p < .01)\). The model with stimulus combination abstract-abstract as reference category yielded a trend for the stimulus combination abstract-face \((t(346) = 1.73, p < .10)\). Post-hoc *t* tests carried out at 22 and 26 weeks to determine whether there was a significant
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Effect of the abstract-face condition on latency of gaze shifting especially at the end of the measurement period failed to demonstrate significant differences.

There were marked inter-infant differences indicated by a significant slope variance for the 16 to 26 week age period ($\chi^2(1) = 6.74$, $p < .01$). The intercept variance also reached significance ($\chi^2(1) = 18.79$, $p < .001$).

Figure 3.6. The mean latency of looks and its standard error in competition trials per stimulus combination between 6 and 26 weeks of age.

Error Analysis

The mean frequency of errors during competition trials between 6 and 26 weeks of age is depicted in Figure 3.2. The frequency of errors declined from 29.4% ($SD = 33.4$) at 6 weeks to 20.3% ($SD = 20.8$) at 14 and 11.9% ($SD = 15.5$) at 26 weeks. The decrease during the age periods from 6 to 9 weeks ($t(108) = -2.13$, $p < .05$) and from 16 to 26 weeks ($t(108) = -2.55$, $p < .05$) turned out to be significant. There was no significant association between the different stimulus combinations and the frequencies of errors. The frequency of errors differed significantly across infants at 12 weeks of age, indicated by a significant intercept variance ($\chi^2(1) = 9.03$, $p < .01$). Furthermore, the estimate of slope variance for the 16 to 26 week age period yielded significance ($\chi^2(1) = 6.15$, $p < .05$), indicating that infants differed significantly in the rate at which the frequency of errors decreased.

The relative frequency of errors which consisted of an eye movement up or down increased over the measurement period from 17.3% ($SD = 24.9$) at 6 weeks to 49.2% ($SD = 38.7$) at 26 weeks. This change, however, did not reach significance, probably due to the large standard deviations. Eye movements which did not reach the target...
were frequent in younger infants (6 weeks, $M = 34.0\%$, $SD = 35.9$; 14 weeks, $M = 29.6\%$, $SD = 37.9$), but decreased significantly between 14 and 26 weeks (26 weeks, $M = 1.6\%$, $SD = 5.0$; $t(19) = 3.94, p < .05$). Looks to the opposite side of the target were relatively frequent, both when infants were young (6 weeks, $M = 28.9\%$, $SD = 38.2$) and at the end of the measurement period (26 weeks, $M = 34.3\%$, $SD = 35.1$) and displayed no significant changes. Eye movements which went beyond the target were rare in very young infants (6 weeks, $M = 3.0\%$, $SD = 7.7$), but their frequency increased as infants grew older (14 weeks, $M = 14.1\%$, $SD = 16.9$; $t(12) = 4.00, p < .05$).

**Discussion**

In this study, which made use of dynamic social and abstract stimuli, we found clear developmental changes concerning the frequency and latency of gaze shifts between 6 and 26 weeks of age. In the non-competition condition, the infants made frequent shifts of gaze to the peripheral stimulus from 10 weeks of age on. The latency of the eye movements decreased between 6 and 16 weeks of age, leveling off thereafter. These developmental trajectories closely replicate the results of the longitudinal study by Butcher et al. (2000), which used only abstract stimuli. In the competition condition, the presence of the central stimulus reduced the probability of looks to the peripheral stimulus in younger infants, as observed in earlier studies (e.g., Aslin & Salapatek, 1975; Harris & MacFarlane, 1974). Around 6 weeks of age, infants made very few shifts of gaze; between 9 and 18 weeks of age, the frequency of shifts of gaze increased rapidly, stabilizing around 80% at 22 weeks. A course of development with a high degree of discontinuity has also been described by Butcher et al. (2000). The findings concerning the latency of gaze shifts are also consistent with findings of earlier studies: The latency of gaze shifts decreased rapidly until 16 weeks of age and then more slowly between 16 and 26 weeks (Hood & Atkinson, 1993). Latencies were significantly longer in the competition than in the non-competition condition when infants were young, but not when they were older (Matsuzawa & Shimojo, 1997). As the studies mentioned earlier (and this one) made use of very different stimulus types (e.g., checkerboards, moving real faces, schematic faces, etc.), it can be concluded that the general pattern of development of disengagement and simple gaze shifts is largely independent of the stimuli used.

Localization of the peripheral stimulus by means of multiple saccades was frequent in younger, but not in older infants, consistent with the findings of Aslin and Salapatek (1975). The overall frequency of errors decreased throughout the measurement period, and, at the same time, the relative frequency of the different types of error changed. Eye movements which failed to reach the target were also frequent in younger infants and can be interpreted as unsuccessful attempts to shift gaze to the peripheral stimulus. Looks beyond the target or up or down were frequently noted errors in older infants. They were typical for the reduced interest for the experimental task, which was observed especially during the last measurement sessions when infants were able to carry out the task easily.
Analyses of the inter-infant differences in the frequency and latency of gaze shifting revealed considerable variance between infants for both frequency and latency measures, as described by Butcher el al. (2000) before. Infants differed both in their overall frequency and latency of gaze shifting and in the rate at which these parameters developed. The largest inter-individual differences were found during the periods of rapid change.

The primary goal of the study was to examine whether the use of different stimuli as central fixation stimulus and peripheral target influences the developmental trajectories of the frequency and latency of gaze shifts. Earlier studies have demonstrated that gross differences in the salience of the peripheral stimulus affect the probability and latency of localization in a non-competition situation (Cohen, 1972; Maurer & Lewis, 1979). In this study, however, we found no effect of type of stimulus on the probability or latency of shifting gaze to the peripheral stimulus in the non-competition condition. This is consistent with our expectations: In the non-competition condition, the central stimulus disappears when the peripheral one appears. As a consequence, only the physical attractiveness and the detectability of the peripheral target should influence the probability of its localization. The absence of such an effect in this study thus suggests that we were successful in creating stimulus pairs in which the two stimulus types were about equally attractive in terms of brightness, movement dynamics, etc.

In the competition condition on the other hand, the different stimulus combinations significantly influenced the probability of gaze shifts. There are three important findings: First, there was a strong effect of stimulus combination. Infants were more likely to shift their gaze when the central stimulus was a face and the peripheral target was abstract, while they were least likely and also slower to shift gaze in the opposite condition (abstract-face). This effect is, however, modified by age. At 6 weeks of age, the infants rarely looked away from the central stimulus, regardless of what it was or what was presented in the periphery, but once attending kept on “staring” at it. The rate of increase in gaze shifting frequency after 6 weeks was greatest for the stimulus combination face-abstract and smallest for the stimulus combination abstract-face compared to the reference categories face-face or abstract-abstract. The differences between the four stimulus combinations were most marked then between 10 and 18 weeks of age. At 18 weeks of age, the frequency of gaze shifting in the face-abstract condition reached about its final level. From 22 weeks on, infants reliably shifted their gaze from the central stimulus to the peripheral target under all stimulus combination conditions. Thus, the infants showed the greatest sensitivity to stimulus characteristics while disengagement was developing but not yet well established. This is consistent with the idea that developing systems are most susceptible to context variables (Thelen & Smith, 1998). We had expected that, after efficient and reliable disengagement had emerged, the influence of competing stimuli with different characteristics might persist in dif-
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ferences in gaze shifting latencies. However, after the period of rapid development, we found no effect of stimulus characteristics on either the frequency or the latency of shifts of gaze.

Second, the data clearly indicate that the central and the peripheral stimulus both influenced the probability of looking to the peripheral stimulus. There were significant differences between the stimulus combinations face-abstract versus face-face and abstract-face versus abstract-abstract, which demonstrates the influence of what was presented to the baby peripherally. This corresponds with the results of Finlay and Ivinskis (1984), who also demonstrated infants’ ability to process stimuli presented in their peripheral visual field. This study shows clearly that stimuli in the periphery are not only processed while the infant is looking to another stimulus in the central visual field, but also influence the infant’s actual looking behavior. The results are also in line with the explanations of sticky fixation as they have been proposed by Hood (1995) or by Johnson (1990). These authors emphasize young infants’ failure in disengaging their gaze (Hood, 1995) and their impoverished orienting to stimuli impinging on their peripheral visual field (Johnson, 1990) when attending to a central stimulus. However, the present results also suggest that infants are able to shift their attention covertly and that it is unlikely that difficulties in moving covert attention – as proposed by Rothbart et al. (1994) – form the basis of the phenomenon of obligatory attention.

Third, the results suggest that – compared to the abstract stimulus – the stimulus featuring the infant’s mother’s face was less able to hold or attract the attention of the infants. This is consistent with findings of studies on face recognition and mother-infant interaction. Very young infants recognize their mother’s face (Bushnell, Sai, & Mullin, 1989; Barrera & Maurer, 1981) and look at it frequently during face-to-face interaction. As they grow older, their interests broaden to include other persons and objects around them. In face-to-face interaction with their mothers, infants of 12 weeks look away from their mother’s face more often (van Wulfften Palthe, 1986), and mothers have to compete and must interact more actively to hold their infant’s attention (Kaye & Fogel, 1980). At the same time, infants have been shown to be very sensitive to disturbances or non-contingent facial activity of their counterparts (e.g., Cohn & Tronick, 1983; Muir & Hains, 1993). We cannot rule out completely the possibility that the use of a video recording of the mother’s face might have had an aversive effect. However, in the scanning experiment in which infants of the same age range were presented with the same stimuli in larger size, no significant differences in fixation time between the abstract and the face stimulus were found. This indicates that the use of a video recording of the mother’s face did not have an aversive effect on the infants (see Chapter 2). At the same time, this finding from the scanning study again suggests that the two stimuli were approximately comparable in terms of their physical characteristics, as the infants did not pay significantly more attention to one of them.
Infants' Shifts of Gaze to a Peripheral Target

The current results clearly support a model which describes the frequency and latency of shifts of gaze as a function of the attractiveness of what is currently attended to in the central visual field as well as of the attractiveness of the competing peripheral target (Hood, Murray, King, Hooper, Atkinson, & Braddick, 1996). Development from obligatory attention to reliable gaze shifting then can be described as reflecting changes in the relative strength of two opposite processes, one maintaining fixation of attention and gaze and the other enabling shifts to a new target. Both types of process are sensitive to characteristics of the competing stimuli.

REFERENCES
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