Chapter 6

Summary and General Discussion

Theoretical Background and Goals of the Study

This thesis investigates the development of two different attentional skills during early infancy: visual scanning and shifting attention and gaze. To examine the world around them, infants have to be able to carry out small, systematic shifts of gaze and to pick up information from different parts of an object they are scanning. This information then has to be integrated with the image already stored in memory and should form the basis for the next eye movements. Besides the relatively small eye movements observed during scanning behavior, larger gaze shifts also play a weighty role in infants' early visual development. Being able to shift gaze away from a stimulus in the central visual field to the periphery is important in order to monitor the environment and identify other potentially interesting targets. While inspecting an object, infants have been observed to shift their gaze away and back regularly. This gaze shifting has been interpreted as a regulation of the flow of visual input to enhance visual information processing (Colombo, 1993). Also during the interaction with another person, infants have been reported to avert their gaze from the other person's face. Again, these gaze shifts are thought to fulfill a regulatory function: When the interaction becomes too intense, arousal is controlled by looking away from the interaction partner (Field, 1981; Stifter & Moyer, 1991).

Both behaviors – visual scanning and shifting of attention and gaze – undergo substantial changes during the first few months after birth. Younger infants have been observed to exhibit long periods of staring once they fixate a stimulus even when there are new stimuli appearing in their peripheral visual field (see e.g., Hood & Atkinson, 1993; Johnson, Posner, & Rothbart, 1991; Butcher, Kalverboer, & Geuze, 2000). They have also been reported to show only very limited scanning of visual stimuli (see e.g., Bronson, 1990, 1996). Around the age of 3 to 6 months, their visual scanning (Bronson, 1990, 1994) and their disengagement behavior (Johnson et al., 1991; Matsuzawa & Shimojo, 1997) have been described as similar to what can be observed in adults.

In experiments on visual processing and attention, the nature of the stimuli used seems to influence the visual behavior of the subjects. This is suggested, for example, by research on visual scanning in adults (see e.g., Mackworth & Morandi, 1967; Antes, 1974) and on gaze shifting in infants (Finlay & Ivinskis, 1984; Butcher et al., 2000). However, the impact of the nature of the stimulus on gaze shifting and visual scanning during infancy has not yet been systematically investigated. This thesis examines the effect of different stimuli on the development of these attentional processes. As stated in Chapter 1, nearly all studies to date have examined visual and attentional development using abstract, mostly unnatural stimuli. So one of the goals was to study attentional development using ecologically relevant as well as abstract stimulus material.

The aim of these studies was to examine the above-mentioned developmental processes during the first half year of infancy. During this period the visual and oculomotor systems mature rapidly, and several visual skills develop (see e.g., Atkinson, 1984). An intensive longitudinal design was chosen. Between the ages of 6 and 26 weeks,

infants were tested six times. So it was possible to describe and compare the timing and tempo of the deployment on the basis of individual developmental trajectories rather than on the basis of isolated snapshots of different infants' performances. Precise registration techniques were adopted to measure eye movements, which served as the indicator for attentional processes: an infrared eye-tracking system and observation accurate to 20 milliseconds.

In addition to studying the "normal" development of attention, it was the goal of this study to examine a group of infants who were born prematurely. Preterm infants have been described on the one hand as being at risk for problems concerning their intellectual functioning during childhood (Breslau & Chilcoat, 2000; Anderson et al., 2003) and adolescence (Botting, Powls, Cooke, & Marlow, 1998). On the other hand, a possibly positive effect of the early visual stimulation that preterm infants are exposed to has been discussed (Fielder, Foreman, Moseley, & Robinson, 1993). The finding that attention patterns in early infancy are related to later cognitive functioning (see e.g., Colombo, 1993; Fagan & McGrath, 1981) emphasizes the importance of comparing the attentional development of healthy full-term and preterm infants.

In the next section, summaries of the chapters 2 to 5 are presented. The first two summaries describe the results of the investigation of the development of visual scanning and gaze shifting respectively in a group of healthy full-term infants. The third summary discusses the associations that were found between the developmental trajectories of visual scanning and shifts of attention and gaze. In the last summary, a comparison of the gaze shifting behavior in full-term and preterm infants is described. The subsequent paragraph contains the conclusions and a general discussion in which I will come back to a number of issues which formed the rationale for the studies. I will explore the theoretical implications of the studies, and present implications and suggestions for further research.

Summaries of the Studies

Developmental Changes in Visual Scanning of Dynamic Faces and Abstract Stimuli

The way infants examine stimuli in their environment changes considerably during the first months of life. When infants are born, they already show complex active scanning, but they are often unable to promptly shift their gaze to interesting stimuli in their visual field (Haith, 1980; Bronson, 1990). Younger babies have been observed to exhibit long fixations of relatively few locations and to examine only the perimeter of visual patterns (Salapatek, 1975; Milewski, 1976). Infants from about 3 months on start to overcome this non-flexible visual behavior and routinely scan various distant parts of a stimulus (Bronson, 1990).

Faces are important and frequent stimuli in the visual environment of a baby. When young infants scan faces, they seem to look at clear contrasts within the face like the edges and the hairline, while infants of 2 months and older look at internal features of a face increasingly frequently (Maurer & Salapatek, 1976). However, most previous

studies of face scanning in infants have used still faces or photographs, which lack functional relevance for the infant.

This study had three aims: First, we wanted to examine how the visual scanning of dynamic stimuli – faces and abstract stimuli – develops throughout early infancy. Although there are indications that moving stimuli are examined in a different way from static displays, infants' scanning of dynamic displays has rarely been investigated. The two stimuli used were the infant's mother's face and an abstract stimulus. The second goal of the study was to investigate whether the scanning patterns elicited by a moving face differed from those elicited by a moving abstract stimulus. As there are hardly any studies which examined face scanning with naturally moving faces as stimuli, the third aim of the study was to investigate which regions of a smiling, moving face infants look at most frequently throughout the first few months of infancy.

The characteristics of scanning patterns were investigated through repeated assessments of 10 infants (5 girls; 5 boys). The infants were examined every 4 weeks from 6 to 26 weeks of age. Sitting in an infant-seat, they watched two different dynamic stimuli displayed one after another on a computer monitor. For the first stimulus a video recording of the infant's mother was made as she was smiling and talking to her baby. This stimulus was combined with an abstract one. To ensure that the abstract stimulus was equivalent to the stimulus featuring the mother's face with regard to its physical characteristics (such as movement dynamics, color range, luminance, etc.) but at the same time contained no meaning or recognizable structures, it was derived from the mother stimulus by carrying out several transformations in a graphic computer program. The videos were presented to the infant on the monitor screen for 30 seconds each. The infants' eye movements during exposure to the stimulus were registered by an infrared eye-tracking system. Number and duration of the infants' fixations were measured. The locations of the infants' fixations while watching their mother's face were also determined. The changes in number, duration, and location of the fixations were examined as a function of age and stimulus.

Infants of all ages attended to the stimuli most of the time they were present. Whereas young babies engaged in single, long fixations, infants from 14 weeks onwards showed more and shorter fixations. They also alternated their scanning of the stimulus with more short looks away from the screen. The way infants scanned the stimuli did not stabilize until 18 weeks, which is slightly later than has been reported in the literature on infants' scanning of static stimuli (Bronson, 1990, 1994). The dynamic nature of the stimuli increased their salience, which may have made them more demanding for the infants. This effect was especially marked for the abstract stimulus. From the 14-week session on, a stable difference in the median fixation duration during inspection of the two stimuli was found. This suggests that infants from this age onwards tended to adapt their scanning behavior to the stimulus characteristics.

When scanning their mother's face, infants directed their gaze at the mouth and eye region most often. Even at the youngest age, infants fixated their mother's eyes

and mouth. There was no indication of an edge preference as has been found in studies using still faces. Between 10 and 14 weeks of age, the quality of the scanning of faces increased significantly, as sticky fixation was overcome, and infants looked at the particularly meaningful regions of the face – the eyes and the mouth – almost the entire time.

The Development of Gaze Shifting between Dynamic Faces and Abstract Stimuli

Being able to shift attention and gaze in a strategic and flexible way forms a prerequisite for many behaviors which play an important role in development during infancy. Young infants explore and monitor their environment by looking around. They regulate the flow of visual input by alternating intense inspections of a stimulus with short looks away and control their arousal by regularly shifting their gaze away from an interaction partner.

However, when the infant is looking at something – for example, a toy or a person's face – the actual gaze shift to a new location is preceded by the disengagement of attention and gaze. Infants of 1 to 2 months of age have been reported to have difficulty shifting attention and gaze away from fixation (Harris & MacFarlane, 1974; Aslin & Salapatek, 1975). This staring behavior has been frequently observed in young infants under diverse circumstances (Hood, Murray, King, Hooper, Atkinson, & Braddick, 1996; Stechler & Latz, 1966; Hopkins & van Wulfften Palthe, 1985) and has been named "obligatory attention" (Stechler & Latz, 1966) or "sticky fixation" (Hood, 1995). The emergence of reliable and rapid disengagement around 3 to 4 months of age (Hood & Atkinson, 1993; Butcher et al., 2000) is an important step towards efficient functioning in different areas such as visual attention, cognition, and self-regulation.

Past research has shown that attributes of the stimuli used influence the infant's visual reaction (see e.g., Cohen, 1972; Butcher et al., 2000; Finlay & Ivinskis, 1984). There are indications that the attributes of both the stimulus which is currently being attended to and the stimulus which appears in the peripheral visual field influence the infant's visual reaction. However, this question has not been systematically addressed to date.

The aim of this study was to examine how the nature of the stimuli affects gaze and attention shifting behavior and how this changes throughout early infancy. Therefore, both a socially meaningful and an abstract stimulus were used. Again, a video of the infant's mother's face and a matched abstract stimulus were used.

Twenty healthy infants (12 girls; 8 boys) carried out a gaze shifting experiment. The measurements started when the infants were 6 weeks old and continued every 4 weeks until the infants reached the age of 26 weeks. The frequency and latency of shifts of gaze to peripheral targets were measured in a competition situation (the fixation stimulus persisted after the target appeared) and in a non-competition situation (the fixation stimulus disappeared when the target appeared). Both stimuli were used as central stimulus or peripheral target, which resulted in four different conditions (face-face, face-abstract, abstract-face, abstract-abstract).

In the non-competition condition, infants shifted their gaze to the peripheral target frequently from the age of 10 weeks on. The latency of the eye movements decreased between 6 and 16 weeks of age and leveled off thereafter. There was no effect of stimulus combination for the non-competition condition.

In the competition condition, however, younger infants looked away from the central to the peripheral stimulus less frequently and more slowly than in the non-competition condition. The disengagement frequency increased rapidly between 6 and 22 weeks of age and stabilized thereafter. The disengagement latency decreased throughout the entire measurement period.

There was a strong effect of stimulus combination 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, while they moved their gaze least frequently and most slowly in the opposite condition (abstract-face). The differences between the four stimulus combinations were most marked between 10 and 18 weeks of age. This suggests that the sensitivity to context variables is highest when disengagement is not yet well established. The results indicated that – compared to the abstract stimulus – the mother's face was less able to hold and attract the infants' attention. This is consistent with the finding that even very young infants know their mother's face well (Barrera & Maurer, 1981) and that their interest broadens to include novel faces and objects in their environment as they grow older (Kaye & Fogel, 1980). The results also demonstrate that the attributes of both the central and the peripheral stimulus influenced the infants' gaze shifting behavior. The transition from sticky fixation to reliable, flexible control over gaze shifts thus can be described in terms of changes in the relative strength of two processes. While one process is maintaining fixation and the other one is enabling gaze shifts to a new target, both seem to be sensitive to the characteristics of the competing stimuli.

Associations between the Developmental Trajectories of Visual Scanning and Disengagement

The visual system of the infant goes through substantial changes during the first few months of life. While young infants' gaze shifting behavior is dominated by the occurrence of "sticky fixation" (Hood, 1995), infants of 3 to 4 months of age start exhibiting fast, flexible disengagement of attention and gaze. In the same period, the ability to scan stimuli in a quick, functional way emerges. Although these mechanisms develop during approximately the same age period, they seem to be based on different neurological structures. While shifts of gaze to a peripheral target are thought to be mediated by the magnocellular pathway, visual scanning has been assigned to the parvocellular pathway. As there are indications that the two pathways may have different developmental courses (Hickey & Peduzzi, 1987), it was one of the goals of this study to compare the developmental trajectories of disengagement and scanning, and it was hypothesized that functional scanning would emerge slightly earlier than

reliable disengagement. There are, however, indications that the magnocellular and the parvocellular pathway are not strictly parallel but have anatomical and functional interrelations (Merigan & Maunsell, 1993). So the second aim of the study was to explore possible associations between the development of disengagement and scanning at the level of the individual infant.

The data of 10 infants who participated in the scanning study and the disengagement experiment were analyzed. Ten healthy infants (5 girls; 5 boys) carried out the scanning and the disengagement task six times between the age of 6 and 26 weeks. In the tasks, two different dynamic stimuli were used: the infant's mother's face and a matched abstract stimulus.

Frequency and latency measures of the eye movements during scanning and gaze shifting were examined using multivariate multilevel models and Monte Carlo analyses. The analyses revealed that both frequency and latency measures continued to change between 16 and 26 weeks for the disengagement task, while there was no significant change for the scanning task after the age of 16 weeks. For the frequency measures, a breaking point after which development stabilized occurred earlier for the scanning than for the disengagement. This is consistent with the account that the parvocellular stream becomes functional slightly before the magnocellular stream. There were no indications for positive associations between the development of scanning and disengagement. Results rather suggested that scanning and disengagement change scores contrasted more with one another than could be expected on the basis of chance. This implies that the dorsal and the ventral stream develop rather independently and do not interact but might even compete for similar resources of development or performance during the first 26 weeks of age.

The Development of Shifts of Attention and Gaze in Preterm Infants

Infants who are born preterm are exposed to visual stimulation earlier in their development than full-terms. Some researchers have suggested that this early visual experience could have a positive influence on the visual development of preterm infants (see e.g., Fielder et al., 1993), others have argued that this early stimulation could be harmful to the immature visual system (see e.g., Friedman, Jacobs, & Werthmann, 1981).

Concerning visual and attentional mechanisms in preterm infants, evidence for an accelerated as well as for a disturbed development has been reported. Findings on gaze and attention shifting in preterm infants are sparse and inconsistent (Butcher, Kalverboer, Geuze, & Stremmelaar, 2002; Atkinson, 2000). As early visual and attentional patterns are related to intellectual functioning in later life (Fagan & McGrath, 1981; Cohen & Parmelee, 1983), it is of great importance to examine early normal development of attention as well as possibly deviant developmental trajectories in high-risk infants.

The first aim of this study was to compare the development of attention and gaze shifting in pre- and full-term infants. As the use of face and non-face stimuli influ-

ences the gaze shifting behavior of infants in a disengagement task (see Chapter 3) and preterm infants have been shown to be visually less responsive to faces (Masi & Scott, 1983), the second goal of the study was to explore possible differences in the impact of the stimulus sort in preterm and full-term infants.

Twenty healthy full-term infants (12 girls; 8 boys) and 10 preterm infants (4 girls; 6 boys) participated in the study. The preterm infants were born after a gestation period between 27.3 and 32.4 weeks and were – despite their rather diverse clinical backgrounds – considered to be developing normally. The infants carried out a disengagement task identical to the one used in the studies described previously. Again, the stimuli consisted of a video of the infant's mother's face and an abstract video. Both stimuli appeared as central fixation stimulus and peripheral target, which resulted in four possible stimulus combinations. The infants were tested every 4 weeks from 6 to 26 weeks of (corrected) age.

The infants' visual reaction to the appearance of the peripheral stimulus was registered (whether infants kept on staring to the center of the monitor, shifted their gaze to the peripheral target, or shifted their gaze away but did not look at the newly appeared target). The latency of gaze shifts was also determined.

The development of the frequency of disengagement was similar in both groups: Infants shifted their gaze effectively in the non-competition condition from 10 weeks on. In the competition condition, the frequency of looks to the peripheral stimulus was significantly lower than in the non-competition condition when infants were young. At 18 and 24 weeks of age, there were no differences in gaze shifting frequency anymore between the competition and the non-competition condition. The gaze shifting latency of both the preterm and the full-term infants decreased throughout the measurement period. Saccadic reaction times were longer in the competition than in the non-competition condition at younger ages as well as at the later measurement points.

There were, however, several significant differences between full- and preterm infants concerning their gaze shifting behavior. At 6 weeks of age, preterm infants had more difficulty overcoming staring behavior in both the competition and the non-competition tasks. Prematurity, however, was also associated with a short-lasting advantage in the latency of disengagement. Thus, preterm infants were on the one hand more likely to show staring behavior but on the other hand quicker in shifting their gaze. This suggests that the triggering of a gaze shift and the actual execution of the eye movement are not necessarily associated. Preterm and full-term infants reacted similarly to the different stimulus combinations. In the competition condition, infants shifted their gaze more frequently when the central stimulus was a face and the peripheral stimulus was abstract. They were also significantly slower in looking away from an abstract stimulus to a face.

One of the aims of the study was to examine whether early visual input is beneficial for early attentional development or whether it might be damaging to the immature visual system. The results of the study do not support either one of the two accounts,

but suggest that prematurity is associated with small differences in visual and attentional development in general. However, the effects were temporary – by the end of the measurement period, the differences in full- and preterm infants' gaze shifting behavior had disappeared.

Conclusions and General Discussion

The aim of this thesis was to investigate the development of visual scanning and shifts of attention and gaze in early infancy. In Chapter 1, several key issues to be examined were set out. In the next section, these issues will be discussed in the light of the results of our investigations. Contextual aspects of development such as the impact of different stimuli or the role of early visual experience in the case of premature birth are treated. The tempo and timing of development of visual scanning and shifts of attention will also be addressed. The use of precise eye movement registration will be evaluated. Finally, theoretical implications and some suggestions for further research are described.

The Role of Different Stimuli

In the experiments described in this thesis, two carefully selected stimuli were used: the infant's mother's face as she was interacting with her baby and a moving abstract stimulus. One reason for this stimulus selection was that many studies on infants' attentional development still neglect the issue of the ecological (ir-)relevance of the stimuli. As a consequence, very little is known about young infants' gaze shifting and scanning behavior when they are confronted with natural stimuli, although there are several reasons to expect that the findings might differ from what has been described on basis of studies which lack ecological validity.

Our results on the development of visual scanning of faces confirmed these expectations. While earlier studies which had used still faces as stimuli reported that infants younger than 2 months show only limited scanning and rarely look at the inner features of the face, in our study, no indication of an edge effect was found. This implies that in a natural face-to-face interaction even infants as young as 6 weeks of age might be able to look at the inner features of the other person's face. The slow, exaggerated way in which mothers tend to talk and move their face when interacting with their babies (Stern, 1974) might help the infants to overcome the edge attraction, which impedes their visual exploration behavior at this young age.

Furthermore, it was our aim to investigate the influence of different sorts of stimuli on the infants' visual behavior. It turned out that different developmental trajectories of visual scanning and gaze shifting could be observed for the abstract and the face stimulus. Less advanced scanning behavior persisted longer when infants were examining the abstract stimulus than when they were scanning their mother's face. In the gaze and attention shifting task, infants were more likely to shift their gaze away from their mother's face and look to an abstract stimulus, and less likely to shift their

gaze from the abstract stimulus to their mother's face in the periphery. Shifts of gaze were also slower in this condition. This effect was found for a group of normal control subjects as well as for preterm infants. The impact of the different stimuli on infants' scanning as well as on their gaze shifting behavior was most marked around the age of 14 weeks, which corresponds approximately with the period of the most rapid development. This finding is consistent with a dynamic systems theoretical approach, which predicts that a skill which is not yet well established is especially sensitive to context variables (van Geert, 1997, 2002).

From the age of about 3 months on, a stable difference in the median fixation lengths while scanning the different stimuli was observed. This finding implies that from the age of about 3 months on, infants started to tailor their scanning behavior to the characteristics of the different stimuli.

These results are particularly interesting as they provide insight into underlying attentional processes. The findings on the development of gaze shifting between different sorts of stimuli revealed that both stimuli – the stimulus presented in the central visual field of the infant and the stimulus used as peripheral target – affected the infants' gaze shifting behavior. While the infants were fixating the stimulus in their central visual field, they were also processing the peripheral target, and the peripheral target also influenced their gaze shifting behavior.

As mentioned above, the two stimuli were designed to be as comparable as possible in terms of their physical characteristics, for example in terms of luminance, color range, and overall movement dynamics. In the gaze and attention shifting task, the abstract stimulus held and attracted the infants' attention better than the face. This is in accord with findings from studies on face-to-face interaction between mothers and infants. While their mother's face is a powerful attractor for infants when they are young (Morton & Johnson, 1991), from the age of about 3 months on, other objects become increasingly more interesting (Kaye & Fogel, 1980), and infants tend to look away from their mother's face more often (van Wulfften Palthe, 1986). The abstract stimulus, however, might still have been new and therefore more attractive. In 3-month-olds, it also elicited a less advanced scanning behavior. It is also possible that the abstract stimulus was slightly more salient due to the fact that it contained more plain areas of the same color and thus more contrast. However, in any case, it was especially challenging for the infant, as its structure and way of movement was still unfamiliar compared to the – by this time – well-known and familiar face of the mother.

Timing, Tempo, and Individual Differences of Development

One of the aims of these studies was to describe the timing and tempo of development of visual scanning and disengagement and the inter-infant differences concerning this change. Therefore, a longitudinal design with six measurement points during the first six months of life was implemented. This design of relatively dense

assessments allowed us to determine more precisely when a stable scanning pattern and reliable disengagement emerged with the different stimuli. In order to explore a possible ordering in the emergence of functional scanning versus the development of disengagement, infants were presented with both tasks throughout the measurement period. Investigating frequency and latency measures, the analyses showed that visual scanning and disengagement improved during the measurement period. The efficiency of disengagement increased rapidly until 16 weeks of age and more gradually thereafter. However, there were no significant changes in scanning behavior anymore during the last measurement period. Furthermore, it could be shown that – for the frequency measures – a stabilization of the developmental changes occurred earlier for visual scanning than for the disengagement of attention and gaze.

Analyses of the inter-infant differences in the development of the frequency and latency of disengagement revealed that there were considerable differences between the performances of different infants. These differences concerned both frequency and latency measures and occurred mainly during periods of rapid development.

The Impact of Prematurity

Another aim of this thesis was to compare the attentional development of a group of infants who were born preterm and a group of full-term infants with uneventful pre- and perinatal histories. As described above, there are two opposite theories on the impact of preterm birth and the resulting extra visual experience. One theory argues that the early visual input could have a positive influence on the infants' visual development (see e.g., Fielder et al., 1993). The other one suggests that this premature visual stimulation might be detrimental to the visual system of the young infant (see e.g., Friedman et al., 1981).

In this thesis, the differences in performance of a group of low-risk preterm infants and a group of healthy full-term infants on a disengagement task were examined. It turned out that young preterm infants had more problems overcoming staring behavior than their full-term age mates, which is indicative of an adverse impact of preterm birth on early attentional processes. At the same time, preterm infants were quicker when shifting their gaze away from one stimulus to a new one in the periphery. This, however, is an indication of a – though short-lasting – advantage in attentional development of the preterm compared to the full-term infant group.

Thus, the findings of this thesis do not provide the basis for a definite decision in favor of either one of these two theories. In my opinion, however, these results rather suggest that neither of these accounts describes the visual and attention development in preterm infants properly. Visual and attentional development depend on the complex interaction of maturational and experience-dependent processes (see e.g., Greenough, Black, & Wallace, 1987). In preterm infants, the timing and sequence of this interaction is disturbed by the preterm birth. Furthermore, they face a high risk for medical complications (such as hemorrhagic and ischemic brain injury or infections)

which might also interfere with their early development. The early visual development of preterm infants is thus affected in many ways, with the result that while some developmental processes may be enhanced, others may be disturbed or delayed.

Studying early attentional development in preterm infants is important for several reasons. As mentioned above, vision and attention have been shown to develop differently in infants born preterm and in healthy full-term infants. However, instead of a having clearly beneficial or harmful impact, the effect of prematurity on infants' early development of vision and attention seems to be complex and heterogeneous. It is of great importance to describe the development of different groups of preterm infants carefully as this forms the basis to understand their abilities and special needs and to develop custom-built interventions. On the other hand, studying abnormal development provides insight into vision and attentional mechanisms in general.

Eye Movement Registration

The first studies using infrared eye-trackers with young infants appeared in the 1960's (Salapatek & Kessen, 1966; Haith, 1969). Since then, this technique has substantially improved. The eye-tracking techniques now available make it possible to measure eye movements and gaze direction with great accuracy and relative ease. Compared to earlier methods, the precision of the measurements has been improved with regard to both the time resolution and the spatial accuracy.

Recent studies have yielded interesting results, not only on the development of infants' scanning of dynamic stimuli, but also on infants' cognitive and perceptual abilities, such as for example the formation of categories (McMurray & Aslin, 2004) or the perception of object unity (Johnson, Slemmer, & Amso , 2004). In the future, the new eye-tracking techniques will probably be implemented by more researchers. Promising topics are processes which to date have mainly been studied using simple habituation measures, such as action perception or object permanence. The use of precise methods to measure eye movements and fixation locations offers the possibility to gain more insight into the actual perceptional processes and early cognitive development.

Aside from the great power and large advantages of eye-tracking methods, researchers should realize that this technique is highly complex and sensitive (see also Haith, 2004). An accurate and reliable measurement of gaze position and eye movements in infants requires a careful positioning of the infant, of the camera and of the stimulus display and a precise calibration. The application of this recording technique with infants as young as 1 to 2 months still forms a great challenge to the researcher because of young infants' poor postural control and limited capability to complete all the steps required for a successful calibration. Table 2.1 in Chapter 2, which presents the amount of time during the stimulus presentation with a complete and reliable measurement at different ages of the infant subjects, illustrates this fact well. However, the diverse opportunities to apply the method and the promising results make the efforts worthwhile.

Theoretical Implications

Existing theories about the underlying mechanisms and the neurological basis of early attentional development differ in how they explain the development of disengagement and the development of visual scanning. Hood (1995) attributes the occurrence of staring behavior to young infants' inability in breaking gaze from a stimulus they are fixating. Johnson (1990), on the other hand, argues that young infants have difficulty generating an eye movement while processing a stimulus which is currently in their central visual field. Rothbart, Posner, and Rosicky (1994), however, suggest that shifts of gaze are preceded by covert shifts of attention, and disengagement problems reflect difficulty shifting attention covertly.

As mentioned above, the results of these studies allow some conclusions concerning the different theoretical accounts. The studies on disengagement showed that infants' reactions in a gaze shifting task depended on the type of stimulus in the central visual field as well as in the periphery. This indicates that infants attended to the peripheral targets even when their gaze was still "stuck" on the central stimulus. This finding makes interpretations which emphasize the role of covert attention less likely but provides support for the theoretical accounts of Hood (1995) or Johnson (1990).

In Chapter 4, the development of visual scanning and of disengagement were compared. As existing theories suggest that these two skills are mediated by different neurological structures, slightly different developmental trajectories were expected. The results confirmed these expectations, and analyses of associations on the level of individual subjects suggested that the two mechanisms seem to develop rather independently.

It has to be kept in mind, though, that a study focusing on behavioral change cannot provide conclusive evidence about underlying neurological substrates (Butcher, 2000). Harder evidence could be provided by studies using imaging methods, as a seemingly identical behavior, for instance, can be mediated by different mechanisms throughout development. However, experimental behavioral studies help sharpen the focus for future research and so form the connecting link between developmental changes observed in daily life and investigations of neurological development.

Implications for Further Research

Understanding attentional processes. There is a large body of research on the early development of visual attention (see e.g., Johnson, 1994; Hood, 1995 for reviews). Understanding how different attentional mechanisms develop is important not only to expand our knowledge about early cognitive development and to detect possibly deviant developmental trajectories early in life, but also to increase our insight into attentional processes in general.

The difficulty disengaging attention and gaze, which is characteristic of the early months of infancy, has been shown to diminish with age (Butcher et al., 2000; Johnson et al., 1991). However, there are indications that also older infants (see Chapter 5; Hood

& Atkinson, 1993) and even adults (Hood & Atkinson, 1993; Fischer, 1986) shift their gaze more slowly between two competing stimuli. There seems to be some resemblance between the performances of infants and adults on disengagement tasks. This suggests that the effect of a stimulus in central vision impeding shifts of gaze to a new location reflects a general characteristic of the human attentional system. However, there are only very few studies which examine the performance on attention tasks at different ages throughout development and which also include adult subjects.

In a pilot study, Butcher and Hunnius (2001) examined the disengagement of attention and gaze using different sorts of stimuli in a small sample of 6 adult participants. The experimental setup and procedure were the same as in the infant studies described in chapters 3 and 4 of this thesis. In the gaze shifting task with competing stimuli, two types of stimuli were used: a video of a still female face and a matched abstract stimulus. It could be shown that the type of stimulus presented in the center and in the periphery affected the speed of gaze shifting. Thus, higher level characteristics – such as meaningfulness – of both the stimulus currently under attention and the target in the periphery are processed and have an effect on the ease with which attention and gaze are disengaged. This effect holds especially for young infants whose ability to disengage attention and gaze is still developing (see Chapter 2), but it is also present in adult gaze shifting behavior.

The above-mentioned examples of research demonstrate how studies on attentional processes in infants and adults can provide information on the underlying maxims of the visual and attentional system in general. To date, this kind of studies are scarce. More research which investigates attentional mechanisms using comparable tasks with very different age groups is needed.

Attentional processes and their development are frequently studied by means of looking behavior. However, in these studies the underlying mechanisms can only be measured indirectly, as changes in looking behavior function as indicators of these mechanisms. So definite conclusions about, for instance, different theoretical accounts or underlying neurological substrates are not always possible. These considerations emphasize the importance of using different methods in studies on attentional development in order to obtain a picture which is as complete as possible. Examples of additional measures are heart rate (see e.g., Finlay & Ivinskis, 1984; Richards, 1997) or imaging techniques (see for reviews, Thomas & Casey, 2003; Richards, 2003). Studies which combine behavioral and more direct measures are needed and will provide new insights into early attentional and visual development.

Exploring the importance of attentional mechanisms for development. Attentional processes play an important role in many daily activities. Reading, recognizing someone you know in a group of people, or walking through a crowded mall are only a few examples of skills which depend on fast, accurate shifts of attention and gaze.

For infants, gaining control over attention and gaze shifts is crucial to be able to explore the environment and to learn about the surrounding world. As mentioned

earlier, the vast majority of studies on infants' cognitive development has made use of global measures such as habituation or preferential looking. These methods were suitable to describe the time course and the circumstances of the emergence of cognitive skills, but reveal rather little about the underlying attentional and perceptual processes. A few studies have tried to link cognitive development and looking behavior. Bronson (1991), for instance, compared scanning patterns of infants who were fast or slow in processing a stimulus. In a recent study, Johnson et al. (2004) examined the relation between infants' way of scanning and their ability to perceive object unity. However, we are only at the beginning of understanding how basic attentional and perceptual processes contribute to complex cognitive skills. Further research promises to provide valuable information on, for instance, visual processing, face recognition or action perception.

The ability to shift attention and gaze swiftly and reliably plays a role not only in early cognitive development, but is also important for young infants' developing emotion regulation skills. Looking away from a stimulus which is annoying or too intense is a way of regulating sensation, and thus it is not surprising that sticky fixation has often been described to cause infants distress (Stechler & Latz, 1966; Tennes, Emde, Kisley, & Metcalf, 1972). Only a few studies have addressed the associations between the development of attention and the development of emotion regulation. Johnson et al. (1991) found that 4-month-olds who disengaged more easily were – according to their mothers' reports – more easily soothed. For infants of 13.5 months of age, Rothbart, Ziaie, and O'Boyle (2003) were able to show that the ability to redirect attention away from distressing stimuli was related to lower levels of negative affect.

As mentioned earlier, early face-to-face interaction also calls on the infants' regulation skills. Infants shift their gaze regularly (Stifter & Moyer, 1991) in order to regulate the visual input, to turn away from an unpleasant (Cohn & Tronick, 1983) or excessively intense interaction. The still-face procedure (Tronick, Als, Adamson, Wise, & Brazelton, 1978) has been used to assess parent-infant interaction, coping, and the regulation of arousal in a situation of face-to-face interaction. Abelkop and Frick (2003) have investigated infants' looking behavior during a still-face situation as well as their performance on attention tasks and found that attentional measures showed moderate stability within cognitive and social contexts. A few studies thus have provided support for the notion that attentional processes affect infants' regulatory skills and social behavior. However, future research should continue to explore the interrelations of attentional and emotional development in infancy.

References

Abelkop, B. S., & Frick, J. E. (2003). Cross-task stability in infant attention: New perspectives using the still-face procedure. *Infancy, 4*, 567-588.

Anderson, P., Doyle, L. W., Callanan, C., Carse, E., Casalaz, D., Charlton, M. P., Davis, N., Duff, J., Ford, G., Fraser, S., Hayes, M., Kaimakamis, M., Kelly, E., Opie, G., Watkins, A., Woods, H., & Yu, V. (2003). Neurobehavioral outcomes of school-age children born extremely low birth weight or very preterm in the 1990s. *Journal of the American Medical Association*, *289*, 3264-3272.

Antes, J. R. (1974). The time course of picture viewing. *Journal of Experimental Psychology*, *103*, 62-70.

Aslin, R. N., & Salapatek, P. (1975). Saccadic localization of visual targets by the very young human infant. *Perception and Psychophysics*, *17*, 293-302.

Atkinson, J. (1984). Human visual development over the first six months of life. *Human Neurobiology*, *3*, 61-74.

Atkinson, J. (2000). *The developing visual brain*. Oxford, UK: Oxford University Press.

Barrera, M. E., & Maurer, D. (1981). Recognition of mother's photographed face by the three-month-old infant. *Child Development*, *52*, 714-716.

Botting, N., Powls, A., Cooke, R. W. I, & Marlow, N. (1998). Cognitive and educational outcome of very-low-birthweight children in early adolescence. *Developmental Medicine and Child Neurology*, *40*, 652-660.

Breslau, N., & Chilcoat, H. D. (2000). Psychiatric sequelae of low birth weight at 11 years of age. *Biological Psychiatry*, *47*, 1005-1011.

Bronson, G. W. (1990). Changes in infants' visual scanning across the 2- to 14-week age period. *Journal of Experimental Child Psychology*, *49*, 101-125.

Bronson, G. W. (1991). Infant differences in rate of visual encoding. *Child Development*, *62*, 44-54.

Bronson, G. W. (1994). Infants' transitions towards adult-like scanning. *Child Development*, *65*, 1243-1261.

Bronson, G. W. (1996). The growth of visual capacity: Evidence from infant scanning patterns. In C. Rovee-Collier & L. P. Lipsitt (Eds.), *Advances in infancy research* (Vol. 11, pp. 109-141). Norwood, NJ: Ablex.

Butcher, P. R. (2000). *Longitudinal studies of visual attention in infants: The early development of disengagement and inhibition of return*. Doctoral dissertation. University of Groningen, Groningen, The Netherlands.

Butcher, P. R., & Hunnius, S. (2001, April). *The influence of abstract and meaningful stimuli on shifts of visual attention*. Poster presented at the Voorjaarsconferentie Nederlandse Vereniging voor Neuropsychologie, Utrecht, The Netherlands.

Butcher, P. R., Kalverboer, A. F., & Geuze, R. H. (2000). Infants' shifts of gaze from a central to a peripheral stimulus: A longitudinal study of development between 6 and 26 weeks. *Infant Behavior and Development*, *23*, 3-21.

Butcher, P. R., Kalverboer, A. F., Geuze, R. H., & Stremmelaar, E. F. (2002). A longitudinal study of the development of shifts of gaze to a peripheral stimulus in preterm infants with transient periventricular echogenicity. *Journal of Experimental Child Psychology*, *82*, 116-140.

Cohen, L. B. (1972). Attention-getting and attention-holding processes of infant visual preferences. *Child Development*, *43*, 869-879.

Cohen, S. E., & Parmelee, A. H. (1983). Prediction of five-year Stanford-Binet scores in preterm infants. *Child Development*, *54*, 1242-1253.

Cohn, J. F., & Tronick, E. Z. (1983). Three-month-old infants' reaction to simulated maternal depression. *Child Development*, *54*, 185-193.

Colombo, J. (1993). *Infant cognition: Predicting later intellectual functioning.* Newbury Park, CA: Sage.

Fagan, J. F., & McGrath, S. K. (1981). Infant recognition memory and later intelligence. *Intelligence*, *5*, 121-130.

Field, T. M. (1981). Infant arousal, attention, and affect during early interactions. In L. P. Lipsitt & C. Rovee-Collier (Eds.), *Advances in infancy research* (Vol. 1, pp. 57-100). Norwood, NJ: Ablex.

Fielder, A. R., Foreman, N., Moseley, M. J., & Robinson, J. (1993). Prematurity and visual development. In K. Simons (Ed.), *Early visual development, normal and abnormal* (pp. 485-504). New York: Oxford University Press.

Finlay, D., & Ivinskis, A. (1984). Cardiac and visual responses to moving stimuli presented either successively or simultaneously to the central and peripheral visual fields in 4-month-old infants. *Developmental Psychology*, *20*, 29-36.

Fischer, B. (1986). The role of attention in the preparation of visually guided eye movements in monkey and man. *Psychological Research*, *48*, 251-257.

Friedman, S. L., Jacobs, B. S., & Werthmann, M. W. (1981). Sensory processing in pre-and full-term infants in the neonatal period. In S. L. Friedman & M. Sigman (Eds.), *Preterm birth and psychological development* (pp. 159-178). New York: Academic Press.

Greenough, W. T., Black, J. E., & Wallace, C. S. (1987). Experience and brain development. *Child Development*, *58*, 539-559.

Haith, M. M. (1969). Infrared television recording and measurement of ocular behavior in the human infant. *American Psychologist*, *24*, 279-282.

Haith, M. M. (1980). *Rules that babies look by.* Hillsdale, NJ: Erlbaum Associates, Inc.

Haith, M. M. (2004). Progress and standardization in eye movement work with human infants. *Infancy*, *6*, 257-265.

Harris, P., & MacFarlane, A. (1974). The growth of the effective visual field from birth to seven weeks. *Journal of Experimental Child Psychology*, *18*, 340-348.

Hickey, T. L., & Peduzzi, J. D. (1987). Structure and development of the visual system. In L. Cohen & P. Salapatek (Eds.), *Handbook of infant perception* (pp. 1-42). New York: Academic Press.

Hood, B. M. (1995). Shifts of visual attention in the human infant: A neuroscientific approach. In C. Rovee-Collier & L. P. Lipsitt (Eds.), *Advances in infancy research* (Vol. 9, pp. 163-216). Norwood, NJ: Ablex.

Hood, B. M., & Atkinson, J. (1993). Disengaging visual attention in the infant and adult. *Infant Behavior and Development*, *16*, 405-422.

Hood, B. M., Murray, L., King, F., Hooper, R., Atkinson, J., & Braddick, O. (1996). Habituation changes in early infancy: Longitudinal measures from birth to 6 months. *Journal of Reproductive and Infant Psychology*, *14*, 177-185.

Hopkins, B., & van Wulfften Palthe, T. (1985). Staring in infancy. *Early Human Development*, *12*, 261-267.

Johnson, M. H. (1990). Cortical maturation and the development of visual attention in early infancy. *Journal of Cognitive Neuroscience*, *2*, 81-95.

Johnson, M. H., Posner, M. I., & Rothbart, M. K. (1991). Components of visual orienting in early infancy: Contingency learning, anticipatory looking, and disengaging. *Journal of Cognitive Neuroscience*, *3*, 335-344.

Johnson, M. H. (1994). Visual attention and the control of eye movements in early infancy. In C. Umiltà & M. Moscovitch (Eds.), *Attention and performance XV: Conscious and nonconscious information processing. Attention and performance series* (pp. 291-310). Cambridge, MA: MIT Press.

Johnson, S. P., Slemmer, J. A., & Amso, D. (2004). Where infants look determines how they see: Eye movements and object perception performance in 3-month-olds. *Infancy*, *6*, 185-201.

Kaye, K., & Fogel, A. (1980). The temporal structure of face-to-face communication between mothers and infants. *Developmental Psychology*, *16*, 454-464.

Mackworth, N. H., & Morandi, A. J. (1967). The gaze selects informative details within a picture. *Perception and Psychophysics*, *2*, 547-552.

Masi, W. S., & Scott, K. G. (1983). Preterm and full-term infants' visual responses to mothers' and strangers' faces. In T. M. Field & A. Sostek (Eds.), *Infants born at risk: Physiological, perceptual and cognitive processes* (pp. 173-180). New York: Grune & Stratton.

Matsuzawa, M., & Shimojo, S. (1997). Infants' fast saccades in the gap paradigm and development of visual attention. *Infant Behavior and Development*, *20*, 449-455.

Maurer, D., & Salapatek, P. (1976). Developmental changes in the scanning of faces by young infants. *Child Development*, *47*, 523-527.

McMurray, B., & Aslin, R. N. (2004). Anticipatory eye movements reveal infants' auditory and visual categories. *Infancy*, *6*, 203-229.

Merigan, W. H., & J. H. R. Maunsell (1993). How parallel are the primate visual pathways? *Annual Review of Neuroscience*, *16*, 369-402.

Milewski, A. (1976). Infant's discrimination of internal and external pattern elements. *Journal of Experimental Child Psychology*, *22*, 229-246.

Morton, J., & Johnson, M. H. (1991). CONSPEC and CONLEARN: A two-process theory of infant face recognition. *Psychological Review*, *98*, 164-181.

Richards, J. E. (1997). Peripheral stimulus localization by infants: Attention, age, and individual differences in heart rate variability. *Journal of Experimental Psychology: Human Perception and Performance*, *23*, 667-680.

Richards, J. E. (2003). The development of visual attention and the brain. In M. de Haan & M. H. Johnson (Eds.), *The cognitive neuroscience of development* (pp. 73-98). Hove, UK: Psychology Press.

Rothbart, M. K., Posner, M. I., & Rosicky, J. (1994). Orienting in normal and pathological development. *Development and Psychopathology, 6*, 635-652.

Rothbart, M. K., Ziaie, H., & O'Boyle, C. G. (1992). Self-regulation and emotion in infancy. In N. Eisenberg & R. A. Fabes (Eds.), *Emotion and its regulation* (pp. 7-23). San Francisco: Jossey-Bass.

Salapatek, P. (1975). Pattern perception in early infancy. In L. B. Cohen & P. Salapatek (Eds.), *Infant perception: From sensation to cognition* (Vol. 1, pp. 133-248). New York: Academic Press.

Salapatek, P., & Kessen, W. (1966). Visual scanning of triangles by the human newborn. *Journal of Experimental Child Psychology, 3*, 155-167.

Stechler, G., & Latz, E. (1966). Some observations on attention and arousal in the human infant. *Journal of the American Academy of Child Psychology, 5*, 517-525.

Stern, D. N. (1973). Mother and infant at play: The dyadic interaction involving facial, vocal, and gaze behaviors. In M. Lewis & L. D. Rosenblum (Eds.), *The effect of the infant on its caregiver* (pp. 187-213). New York: Wiley.

Stifter, C. A., & Moyer, D. (1991). The regulation of positive affect: Gaze aversion activity during mother-infant interaction. *Infant Behavior and Development, 14*, 111-123.

Tennes, K., Emde, R., Kisley, A., & Metcalf, D. (1972). The stimulus barrier in early infancy: An exploration of some formulations of John Benjamin. In R. R. Holt & E. Peterfreund (Eds.), *Psychoanalysis and contemporary science* (pp. 206-234). New York: Macmillan.

Thomas, K. M., & Casey, B. J. (2003). Methods for imaging the developing brain. In M. de Haan & M. H. Johnson (Eds.), *The cognitive neuroscience of development* (pp. 19-41). Hove, UK: Psychology Press.

Tronick, E. Z., Als, H., Adamson, L., Wise, S., & Brazelton, T. B. (1978). The infant's response to entrapment between contradictory messages in face-to-face interaction. *Journal of the American Academy of Child Psychology, 17,* 1-13.

van Geert, P. (1997). Variability and fluctuation: A dynamic view. In E. Amsel & K. A. Renninger (Eds.), *Change and development: Issues of theory, method, and application* (pp. 193-212). Mahwah, NJ: Erlbaum.

van Geert, P. (2002). Developmental dynamics, intentional action and fuzzy sets. In N. Granott & J. Parziale (Eds.), *Microdevelopment: Transition processes in development and learning* (pp. 319-343). Cambridge, UK: Cambridge University Press.

van Wulfften Palthe, T. (1986). *Neural maturation and early social behavior: A longitudinal study of mother-infant interaction.* Doctoral dissertation. University of Groningen, Groningen, The Netherlands.