Through the Eyes of an Infant

Hunnius, S.

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Chapter 1

Introduction

Anybody who has ever observed a baby of a few weeks of age looking around and examining his environment has undoubtedly noticed how different his visual behavior is from that of an adult. A young infant tends to move his eyes slowly, and often it seems as if he gazes vacantly in front of him. He likes to look at patterns with high contrast, so the locations that interest him can be the dark frame of a painting on a light colored wall or the knob of a drawer. From time to time, it seems as if the baby's gaze gets "stuck" at one location for 10 to 20 seconds, and the infant may keep on staring there, although there may be other equally salient things to look at in his environment, for example a colorful toy. If a moving object catches his eye, he may follow it, as long as it is not going too fast.

Were we to observe the same infant 3 or 4 months later, we would see that his visual behavior has changed dramatically. The infant now examines objects by scanning them quickly and systematically. Complex, colorful, and moving stimuli attract his attention particularly easily. The baby tends to alternate his intense inspections with brief looks away. His eye movements are fast, and he tracks moving objects or persons easily.

Vision plays a crucial role in the daily life of an infant. As young infants are unable to move around or to grasp objects easily, they explore their environment and learn about the world by looking. Looking is also one of the most important ways in which infants communicate with their caretakers. Face-to-face interaction forms the beginning of social communication and plays an important role in the bonding of infant and caretaker.

The ability to carry out fast, accurate shifts of gaze serves as the basis for visual information processing and communication in early infancy. Accordingly, the developmental changes in the visual system sketched above are of great importance. The question which factors enable or hinder its functional development therefore deserves precise investigation.

This dissertation deals with the developmental changes in attention and gaze shifting behavior which occur during the first few months of life. It reports the results of an intensive longitudinal study on visual exploration behavior and the disengagement of attention and gaze from a fixated stimulus. The purpose of the study was to examine these issues using dynamic stimuli and to investigate the influence of different stimuli on young children's visual behavior. Abstract and socially relevant stimuli were contrasted. In addition to examining a group of healthy full-term infants, it was the goal of this study to describe the nature and extent of differences in the development of these attentional processes between full-term infants and infants born prematurely. A sequence of six measurements during a period of five months, in which rapid development of the visual system was expected, was supposed to provide exact information on the timing and tempo of development. Precise techniques to measure visual fixations and eye movements were employed.

This introductory chapter begins with an overview on vision, attention, and eye movements in early infancy. Different methods of measuring eye movements are discussed. Then, the biological mechanisms which are thought to underlie shifts of gaze and attention and their development are expounded. Next, different aspects of the role of visual input are examined: The impact of exposure to visual stimulation is considered, and the question is raised whether (extra) visual experience influences the early visual and attentional development. Then, the relation between the sort of visual input and its processing is investigated. In this context, the importance of using ecologically valid stimuli in experiments is discussed. The chapter ends with a description of the goals of this study and an outline of the dissertation.

Attention Shifts and Eye Movements in Infancy

Shifts of gaze and shifts of attention are tightly associated, although they do not necessarily occur conjointly (Stelmach, Campsall, & Herdman, 1997). Whereas overt shifts of attention involve saccadic movements of the eyes in order to align the fovea of the retina, the focus of attention can also be shifted covertly in absence of eye or head-movements (Wright & Ward, 1998). It has been argued that covert attention shifts occur as premotor activity in the preparation of eye movements but without an actual gaze shift (Rizzolatti, Riggio, Dascola, & Umiltà, 1987). In daily life, however, attention and gaze shifting are usually very closely joined.

Gaze and attention shifting has been studied extensively in diverse research fields. For example, topics as diverse as stimulus discrimination, memory, or concept formation have been investigated using the habituation paradigm. This procedure is based on the idea that the way infants look at and away from a stimulus signifies their processing of information about the stimulus (Bornstein, 1985). In addition, variables measured during infant habituation studies – as duration of the first fixation, the total fixation time, or the duration of the longest fixation – have been shown to predict later cognitive abilities (for reviews, see Colombo, 1993; Slater, 1995).

Also, gaze shifting behavior has been analyzed in studies on social development. Eye contact has been studied as one of the earliest forms of social interaction and as an important factor for the attachment of mother and infant and for the quality of their relationship (Keller & Gauda, 1987; Schölmerich, Leyendecker, & Keller, 1995). Research on face-to-face interaction between mother and infant has examined infants' looking to or away from their mothers' face and has revealed that infants tend to regulate the intensity of an interaction by shifting their gaze (Field, 1979; Stifter & Moyer, 1991).

Furthermore, it has been shown that children who are able to disengage attention and move gaze more easily, are less susceptible to distress and are more soothable (Johnson, Posner, & Rothbart, 1991). These various examples emphasize the importance of shifts of attention and gaze in infancy. They also illustrate that attention and gaze shifting behavior has been studied to gain insight into very different areas of infant psychology, such as visual exploration, early communication, or arousal modulation.

Also diagnostic instruments which assess infants' developmental status during the neonatal or the infant period are among other tasks based on items which require visual orientation to animate and inanimate stimuli or shifting gaze between two objects (Neonatal Behavioral Assessment Scale, NBAS, Brazelton & Nugent, 1995; Bayley Scales of Infant Development, BSID-II, Bayley, 1993) .

Development of Vision

For a long time, it was commonly accepted that newborn and young infants perceive their environment in an extremely impoverished way (see e.g., Dewey, 1935; Pratt, 1954; see also Stone, Smith, & Murphy, 1973, p. 3-4 for more examples). Also Wilhelm Preyer, whose book "Die Seele des Kindes" (1882) is often considered as the beginning of infant psychology, reported the relative immaturity of the visual system of a human newborn and, as one of the first, sought to examine a young infant's reactions to visual stimuli. William James described the early experiences of an infant as "one great blooming, buzzing confusion" (James, 1890, Vol. 1, p. 488), and also Jean Piaget (1936, 1937) emphasized the strong sensory limitations during infancy. It was not before the 1960s that researchers started to specify what exactly the perceptual limitations of early infancy are, and concentrated on describing what young infants are able to see.

It is clear that young infants' vision falls far short of adult standards. The optical state of the eye, though, seems to be quite good in the newborn. Infants can accommodate on targets which are relatively close already during the first days of life (Braddick, Atkinson, French, & Howland, 1979; Haynes, White, & Held, 1965). Visual acuity in newborns, however, has been shown to be about 1/30 of the acuity of adult levels and to have improved by a factor of 3 to 4 by 5 months of age (Fantz, Ordy, & Udelf, 1962). However, it has been argued that unsharp vision does not handicap the infants, as they can still perceive relevant features at a proper distance, but might instead even help them to prevent excessive visual stimulation (Maurer & Maurer, 1988).

Even very young infants seem to have some form of color vision, and it is probably very similar to that of adults. However, infants of 1 month of age have been shown to be unable to discriminate certain colors (e.g., green and yellow), but by 2 months they succeed in making most color discriminations (Clavadetscher, Brown, Ankrum, & Teller, 1988). In a complex colorful stimulus, young infants thus probably do not distinguish as many different colors as adults would, and colors presumably appear less intense to them than they do to adults. When infants are 3 to 4 months old, their color vision is at a relatively adult level (Teller & Bornstein, 1987).

To sum up, although infants' vision is not yet fully mature during the first few months after birth, they see well enough to respond appropriately to relevant aspects of the environment and function effectively in their roles as infants (Hainline, 1998; Hainline & Abramov, 1992).

Developmental Changes in Visual Attention and Eye Movements

Eye movements emerge already during prenatal development (Prechtl, 1984). They have been observed in 16 to 18 weeks gestation, but they are naturally not associated with visual stimuli until exposure to light after birth. When infants are born, they have been demonstrated to prefer stimuli and objects with simple patterns and high contrast (Fantz & Yeh, 1979). They are able to localize a visual target, although in a rather inaccurate and unreliable way (Atkinson, 1992). Once they look at a stimulus, they scan it actively, but tend to fixate only limited parts of it (Haith, 1980; Bronson, 1990) and to ignore other stimuli in their visual field (Bronson, 1996; Haith, 1980; Salapatek, 1975). During the first weeks of life, infants have also been shown to look especially at edges or outer contours of a stimulus pattern ("contour salience effect", Bronson, 1991) and not to attend to stationary inner parts of a stimulus ("externality effect", Salapatek, 1975; Milewski, 1976). However, if the internal elements of a pattern are moving, they are more likely to be fixated even by very young infants (Bushnell, 1979; Girton, 1979). Newborns are able to track moving stimuli (Tauber & Koffler, 1966), although they tend to do it not in a smooth, but in a saccadic, step-wise way and tend to lag behind the movement of the stimulus (Aslin, 1981). Around 2 months of age then, infants have been observed to follow a moving visual target smoothly (von Hofsten & Rosander, 1996), but it is not before about 3 months that infants predict the movement of the stimulus in an anticipatory way and do not lag behind anymore (Aslin, 1981).

Between approximately 1 and 3 months of age, infants have trouble looking away from a stimulus, once their attention has been engaged, and they may exhibit long periods of staring. This phenomenon of disengagement difficulty has been called "sticky fixation" (Hood, 1995) or "obligatory attention" (Stechler & Latz, 1966). It can be observed in a laboratory context (Hood, Murray, King, Hooper, Atkinson, & Braddick, 1996; Aslin & Salapatek, 1975), in free looking situations (Stechler & Latz, 1966), during social interaction (Hopkins & van Wulfften Palthe, 1985), and is also reported frequently by mothers and other caretakers as an every-day experience. As infants grow older, disengaging attention and shifting gaze away from a stimulus becomes increasingly efficient. By 4 months of age, infants are able to shift gaze easily and rapidly, and staring behavior becomes rare (Hood & Atkinson, 1993).

When infants become more capable of achieving a balance between engaging and shifting attention, also their scanning behavior changes. Infants of about 3 months have been described to explore the stimulus under examination more consistently and more extensively (Bronson, 1996). They exhibit more brief fixations and scan more rapidly over the entire array of stimulus figures. Salient parts of a stimulus still attract the infants' gaze, but they have gained volitional, strategic control over their scanning behavior (Bronson, 1994).

From 3 months on, infants not only start anticipating stimulus movement during visual tracking, but also begin to form expectations about the locations of upcoming stimuli and may even initiate an eye movement in advance (Haith, Hazan, & Goodman, 1988; Canfield & Haith, 1991). The increasing intentional control over their eye movements enables infants of 4 to 5 months to examine their environment in an efficient and flexible way. They can shift their gaze fast and reliably between and within visual stimuli and are able to direct their gaze to relevant locations. Eye movements are now generated in accordance with the strategic demands of ongoing information processing. When scanning familiar stimuli, recursive scanning patterns can be observed (Bronson, 1982). During face-to-face interaction, infants of 3 months and older tend to shift their gaze away more often, either in order to regulate arousal (Stifter & Moyer, 1991) or to explore other locations which are becoming increasingly more interesting to them (Kaye & Fogel, 1980).

Measuring Eye Movements in Infants

Vision and human viewing patterns have fascinated researchers for a long time (see e.g., Müller, 1826; Preyer, 1882). Eye movements and fixations in infants have been observed in order to address very different topics, such as visual scanning (Haith, 1980; Bronson, 1982) and visual processing (Bronson, 1991), the acquisition of object knowledge (Johnson & Johnson, 2000; Johnson, Slemmer, & Amso, 2004), or the formation of categories (McMurray & Aslin, 2004).

Probably the most common method of studying eye movements is simple observation of gaze. There are two more precise methods of measuring eye movements and fixations: electro-oculography (EOG) and corneal-reflection photography. EOG is based on measuring the change in electrical potential which accompanies the rotation of the eye. However, this method has several limitations, especially when used with young infants (Aslin & McMurray, 2004). It is particularly sensitive to artifacts and requires the application of electrodes on the subject's face. Furthermore, EOG provides only data on the relative displacement of the eye and no information about where on the stimulus the subject is looking.

For corneal reflection eye-tracking, an (infrared) light source is used to create a reflection off the front surface of the eyeball, while the eye is recorded on video. The reflection is displaced when the subject moves fixation, and the information about the relative position of the corneal reflection with respect to the center of the pupil and its change is used to determine whether an eye movement took place. However, to gather information about the location of fixation, the corneal reflection eye-tracking system has to be individually calibrated before the measurement in order to map the output data onto the field the subject is looking at (Bronson, 1983; Harris, Hainline, & Abramov, 1981).

The technique of infrared corneal photography has been applied to human infants first in the 1960s (Salapatek & Kessen, 1966; Haith, 1969) and has been improved in many respects since then. The sampling rate has been increased from 2 - 6 Hz to 30 - 60 Hz (Aslin, 1981; Hainline, 1981; Bronson, 1982) and even to 120 and 250 Hz. The increased temporal resolution has greatly amended the accuracy in determining fixation durations. Another recent improvement is to have the camera mounted on a motor-driven base which moves in order to maintain the image of the eye in the camera's field-of-view and compensate for head-movements of the infant. However, large or rapid head-movements still formed a problem for a corneal photography eye-tracking system. This resulted in experimental setups in which the infant's head had to be restrained. As this is a quite unnatural situation and can be distressing for the infants, the implementation of a head-tracker, a position-sensing system that monitors head movements and communicates this information to the eye-tracking system, means an important innovation.

Today, it is thus possible to examine how infants look at different stimuli in a more precise and at the same time more natural way than ever before. However, there are still some problems, which form a challenge for the researcher: The accuracy of the measurements of the location of fixations depends largely on the quality of the calibration carried out. For working with infants as young as 6 weeks of age, custom-built calibration procedures have to be developed in order to make the infants fixate a sequence of (preferably many) calibration points. Furthermore, young infants tend to have poor postural control, which requires several accommodations of the experimental setup, including the position of the infrared camera and the stimulus display. To sum up, measuring eye movements in infants remains a challenging task for the researcher as it is tried to apply a complex and highly sensitive technique to delicate subjects, who are indifferent to instructions.

Neurophysiological Models of Eye Movement Generation in Adults

After this overview on vision and eye movements in infancy and on early visual and attentional development, the question remains which neurophysiological processes underlie the described functions and developmental changes. The following two paragraphs are dedicated to this question.

Eye movements are controlled by different cortical and subcortical structures. Many neurobiological models proceed on the assumption of two visual systems, a phylogenetically older retinotectal system and a newer geniculostriate system. Early anatomical studies had already identified two distinct streams from the retina through the brain, but the functional distinction arose from studies in the 1950s en 1960s (see e.g., Sprague & Meikle, 1965). The first models featuring the distinction between two routes were proposed by Trevarthen (1968) and Schneider (1969). Trevarthen (1968) described an "ambient" system for movement control and a "focal" system for object vision. Schneider (1969) suggested that the tectal system defines "where" an object is located and initiates an orienting response and the newer cortical mechanisms are about "what" there is to see precisely in the selected location. In 1982, Ungerleider and Mishkin revised the dichotomy into a ventral versus a dorsal cortical stream. According to this model, the ventral stream, concerned with the "what"-aspects of an object as color, form, or face recognition, is assigned to the inferotemporal cortex. The identification of spatial location, on the other hand, is thought to be subserved by the dorsal stream ("where"), which is anchored by the posterior parietal cortex. The dorsal versus ventral distinction has been associated with a division earlier in the visual pathway, namely between the parallel magnocellular and parvocellular systems (Livingstone & Hubel, 1988; Shapley & Perry, 1986; Van Essen & Maunsell, 1983). These two systems are anatomically segregated at the retina and the lateral geniculate nucleus and project to different parts of the primary visual cortex. The parvocellular based system subserves form and color vision, whereas the magno cells are specialized in movement perception and some aspects of stereoscopic vision. However, the simple distinction into these two parallel systems has been questioned recently, as there are many interactions in visual processing between the magnocellular and the parvocellular stream (see e.g., Cowey, 1994; Merigan & Maunsell, 1993 for reviews).

One of the currently predominant models of eye movement generation is the one developed by Peter Schiller (Schiller, 1985, 1998). His recent model (Schiller, 1998) is based on adult primate electrophysiological and lesion data and also distinguishes between two different, but partly overlapping, neural systems of eye movement control: the anterior and the posterior eye movement control system. The anterior system is responsible for saccades that are voluntary or planned (as e.g., scanning behavior), whereas the posterior system generates fast, reflex-like eye movements and orienting responses, as they occur, for example after the sudden appearance of a salient stimulus in the periphery.

The streams of the anterior system originate in retinal ganglia, which are specialized for the analysis of fine detail and color (Richards & Hunter, 1998). They project through the lateral geniculate nucleus to the striate cortex, and from there they run through the temporal or the parietal lobe to the frontal eye fields. Then they project via the basal ganglia and the superior colliculus to the eye movement centers of the brain stem. However, these brain stem structures also receive direct input from the frontal eye fields within the anterior eye movement control system.

The posterior eye movement control system receives the majority of its input from the retinal ganglia, which are located in the peripheral retina and are specialized for the detection of sudden changes (Richards & Hunter, 1998). Its pathways run via the lateral geniculate nucleus to the striate cortex. Then, they project – partially via the parietal lobe – through the basal ganglia to the superior colliculus.

The activity of the superior colliculus thus is controlled via both systems, the anterior as well as the posterior eye movement control system. Their excitatory or inhibitory input plays an important role in the generation of eye movements to interesting location and at the same time in the inhibition of reflexive eye movements in order to ensure a well-organized input of visual information. However, within the anterior eye movement control system, there is also a pathway which bypasses the superior colliculus and hereby enables the generation or inhibition of eye movements independently from collicular control.

Neuropsychological Models of Attentional Development in Infants

The visual and attentional behavior of an infant is largely determined by the developmental state of the brain structures which form the visual system. Changes observed in behavior and neural correlate can be due to maturation, but can as well be a response to experience (Greenough, Black, & Wallace, 1987). Also, there are several examples of neural and behavioral changes that are the result of an interaction between intrinsic factors and environmental aspects (Johnson & Morton, 1991; Greenough, Black, & Wallace, 1987).

Anatomical (Conel, 1939-1967) and PET scan studies (Chugani, 1994) have demonstrated that, generally, subcortical brain structures are more mature at birth than cortical visual mechanisms. The superior colliculus is one of the most mature structures involved and is thought to play a crucial role in the generation of eye movements during early infancy.

Gordon Bronson was one of the first to propose a model which applied findings from research on adult neurological systems (e.g., Schneider, 1969; Trevarthen, 1968) to infant visual behavior (Bronson, 1974). According to his model, the early development of visual attention can be viewed as a shift from subcortical to cortical processing. Visual behavior in the newborn thus is mainly controlled by means of a phylogenetically older visual system. It is only by 2 to 3 months of age that the locus of control switches to the primary visual system and its mainly cortical pathways.

However, the original model proposed by Bronson (1974) based on the "two visual systems" (Schneider, 1969) and a subcortical-cortical dichotomy has been criticized as being too simplistic and incomplete (Atkinson, 1984; Johnson, 1990). Also, the early presence of certain perceptual abilities has given rise to the notion that there is at least some degree of cortical functioning at birth (e.g., Slater, Morison, & Somers, 1988). It is now known that several comparatively independent cortical streams of visual processing exist (see e.g., Van Essen, 1985) and that they undergo various forms of developmental changes, such as myelination, synaptic generation, neural innervation, synaptic pruning, and neurotransmitter development (see e.g., de Haan & Johnson, 2003).

Bronson's most recent model (Bronson, 1994, 1996) is based on two pathways – the "striate" and the "poststriate networks" (Bronson, 1996) – which are similar to the posterior and anterior eye movement control system proposed by Schiller (1998, 1985) and the assumption that the changes observed in early visual behavior can be explained by reference to the maturational state of these pathways. During the first few weeks of life, eye movements are mainly controlled by the striate networks. These areas are highly responsive to stimulus salience, accordingly, young infants' visual behavior tends to be mainly salience-guided. Once the fovea is aligned with an area of high salience, fixations are often concentrated around this area because – due to the anatomical structure of the retina – close salient areas produce higher striate activity than comparable areas further away. As highly salient stimuli produce long lasting activity, fixations tend to be long in young infants. From about 6 weeks of age on, the poststriate networks with their pathways through the parietal and frontal cortex become increasingly effective. This system comprises areas that are able to encode the location and the form of visual stimuli. These pathways project to the superior colliculus and to the brain stem centers which directly generate eye movements. Older infants thus can draw on these poststriate capacities to override salience effects and move their eyes intentionally to locations of interest.

Also the model of visual and attentional development by Mark Johnson (1990, 1995; Johnson, Gilmore, & Csibra, 1998) refers to the eye movement control system by Schiller (1985), particularly to four distinct pathways. Johnson assumes that the characteristics of visually guided behavior mirror the degree of functionality of the four pathways – three cortical and one subcortical – and that the developmental state of the primary visual cortex determines which of theses pathways is functional. In correspondence with the inside-out pattern of postnatal development in the cerebral cortex (see e.g., Nowakowski, 1987; Rakic, 1988), he hypothesizes that the lower layers tend to be more capable than more superficial ones. In newborn infants, only the deeper layers of the primary visual cortex are functional, and the visually guided behavior is controlled predominantly by the subcortical pathway. According to Johnson, the saccadic pursuit tracking observed in young infants (Aslin, 1981) and the phenomenon that young infants do not attend to a stationary pattern within a larger frame or pattern ("externality effect") are characteristic of visual behavior that is controlled subcortically. Other behaviors, such as early pattern recognition (Slater, Morison, & Rose, 1982) or orientation discrimination (Atkinson, Hood, Wattam-Bell, Anker, & Tricklebank, 1988) suggest at least some cortical functioning also in the newborn infant. During the first month, the nigral pathway, which is an inhibitory input to the superior colliculus from several deeper layers of the primary visual cortex, becomes increasingly functional. According to Johnson, this unregulated tonic inhibition has as a transient consequence the infants' disengagement difficulties, known as "sticky fixation" or "obligatory attention". Around 2 months of age, infants begin to show smooth visual tracking. According to Johnson, the onset of this behavior coincidences with the functioning of the middle temporal area pathway. During the third and fourth month then, the pathways involving the frontal eye fields become functional, as the upper layers of the primary visual cortex mature. This leads to a more differentiated regulation of collicular activity and ends the tonic inhibition, which caused the staring behavior. Infants are now able to move their gaze intentionally from fixation to other locations of interest and to generate anticipatory eye-movements.

The models by Johnson and Bronson succeed in explaining the most important developmental changes of visual behavior in infancy, but they differ in the underlying processes which they assume to be involved. However, both models have strongly influenced the models proposed by other researchers (see e.g., Atkinson & Braddick, 2003; Richards & Hunter, 1998).

Premature Birth and the Role of Early Visual Input

Development emerges from the interaction of many different factors. As described earlier, maturation of the eye and of the brain play a crucial role in the development of visual and attentional skills. However, other factors might be equally important. The next two sections address different aspects of the role of environmental factors. First, early exposure to visual input caused by premature birth is discussed. The next paragraph focuses on the impact of the nature of visual stimulus material on young infants' visual and attentional performance.

When infants are born prematurely, they are confronted with a very different environment than they experience in utero much earlier than their full-term age-mates. The preterm birth also puts them at risk for severe medical complications such as breathing problems, infections, and brain damage. In neonatal intensive care units (NICUs), many efforts are being made to create the optimal conditions according to the infants' physiological needs (e.g., temperature and nutrition) and psychological requirements (e.g., stimulation and contact). A large amount of research on the optimal treatment of preterm infants has been carried out to date (see e.g., Holditch-Davis & Black, 2003; Wolke, 1987).

One important difference between full- and preterm infants is that infants born prematurely are confronted with visual input earlier in life than full-term infants. There are contrasting theories about the impact of this extra experience on the visual development of the infant. One theory implies that healthy preterms benefit from their early exposure to the visual world (Fielder, Foreman, Moseley, & Robinson, 1993). This account is supported by Hunt and Rhodes (1977), who found that during the early months preterm infants have higher scores on the mental scale (MDI) of the Bayley Scales of Infant Development (Bayley, 1969), a scale which – when very young infants are tested – relies mainly on the infants' visual responses. Also, superiority of visual acuity (Sokol & Jones, 1979; Mohn & van Hof-van Duin, 1986) and more mature focusing and tracking of moving stimuli (Dubowitz, Dubowitz, Morante, & Verghote, 1980; Bloch, 1983) have been described in preterm infants compared to full-terms of the same (corrected) age.

On the other hand, it has been suggested that the immature visual system might suffer from early exposure to visual stimulation (Friedman, Jacobs, & Werthmann, 1981; Turkewitz & Kenny, 1985). In accord with this, there are several studies reporting that preterm infants have longer look durations in habituation studies (Rose, Feldman, McCarton, & Wolfson, 1988; Spungen, Kurtzberg, & Vaughan, 1985) as well as difficulties localizing new stimuli (Landry, Leslie, Fletcher, & Francis, 1985). In free play, they also pay less attention to toys (Landry & Chapieski, 1988).

It has been shown that preterm infants' problems concerning visual processing and recognition memory persist throughout the first year of life (Rose, Feldman, & Jankowski, 2001; Rose, 1983). In later childhood these infants tend to have lower scores on attention tests (Taylor, Hack, & Klein, 1998) and cognitive scales (Wolke & Meyer, 1999). Even in early adolescence, they have been shown to be at risk concerning their intellectual functioning (Botting, Powls, Cooke, & Marlow, 1998).

To summarize, there are two major reasons to examine preterm infants' development of vision and attention: As described above, preterm infants tend to perform more poorly on tasks requiring attentional and processing skills, even later in childhood. Sorting out precisely how the development of vision and attention is different in preterm infants is crucial in order to understand their eventual deficits and to develop suitable and effective interventions. On the other hand, examining healthy preterm and full-term infants is of great scientific interest, as it offers the possibility to learn more about the roles of maturation and experience in visual and attentional development.

The Role of the Nature of the Stimuli

In 1977, Urie Bronfenbrenner provokingly postulated that "much of contemporary developmental psychology is the science of the strange behavior of children in strange situations ... for the briefest possible periods of time" (Bronfenbrenner, 1977, p. 513). Still, more than 25 years after Bronfenbrenner's well-known criticism and about 60 years after Egon Brunswik introduced the concept of ecological validity (Brunswik, 1943), developmental psychologists struggle with the demand of producing research that allows generalizing to real world phenomena.

A prominent topic in the debate around ecological validity of experimental studies is the choice of stimuli (Schmuckler, 2001). The stimulus material used for instance in studies on cognitive processes has been criticized as "abstract, discontinuous and marginally real", and results of these kind of studies have been suspected to "be irrelevant to the phenomenon that one would like to explain" (Neisser, 1976, p. 33, 34). Lewkowicz (2001) correctly remarks that setting up an experiment with ecologically valid stimulus material does not necessarily mean creating conditions which are as naturalistic as possible. Instead, it is essential to identify the relevant aspects of the natural environment that control the infant's responsiveness and to capture them in the stimuli used.

However, when examining the current research on infants' development of perception and attention, one can still question the ecological validity of a large number of studies. For example, much we know regarding attention, perceptual responsiveness, and information processing during infancy is based on experiments using unimodal stimuli, although it has been shown that multimodal stimulation can elicit enhanced responsiveness (Bahrick, 1992, 1994).

Another example are studies on the perception and scanning of faces. Most of these studies have been carried out with schematic drawings (e.g., Maurer & Maurer, 1988; Caron, Caron, Caldwell, & Weiss, 1973) or photographs of faces (e.g., Hainline, 1978) or manikins (e.g., Carpenter, 1974). When real faces have been used, they often were still faces (e.g., Maurer & Salapatek, 1976; Bronson, 1982). The generalizability of the findings from these studies is unknown. At the same time, there are several reasons to assume that infants' reactions to a naturally moving, smiling face might be considerably different. First, it has been demonstrated that moving stimuli – both faces (Wilcox & Clayton, 1968; Haith, Bergman, & Moore, 1977) and non-face stimuli (Tronick, 1972) – attract more attention in infants. Further, there are indications that moving stimuli are regarded differently than static displays (Bronson, 1990; Girton, 1979; Johnson & Johnson, 2000). Examples like these emphasize the importance of complying with the demands of ecological validity, especially when investigating young infants skills and competences.

Issues of Further Investigation and Goals of the Study

The developmental changes which occur in the visual attentional behavior of young infants have been studied in detail. However, nearly all of those studies have used only unnatural, often abstract stimulus material. Information on the early development of attention and eye movements in the context of natural stimuli is largely missing (but see e.g., Bornstein & Ludemann, 1989). Consequently, the first aim of the current study was to fill in this gap by examining the development of two important attentional skills – disengagement of attention and visual scanning – using two carefully selected stimulus types. As an ecologically valid stimulus, a video recording of the face of each infant's mother was used. Further, it was chosen to present the mother's face in a natural way. Thus, for the video recording she was filmed moving and smiling as she would do during a face-to-face interaction with her baby. In order to test the influence of different sorts of stimuli, it was also chosen to use a second, abstract stimulus which matched the actual mother video.

The majority of the studies on the development of gaze and attention shifting and visual scanning presents only cross-sectional data with broad age intervals. Studies which provide longitudinal data with several dense measurement occasions are scarce (but see e.g., Butcher, Kalverboer, & Geuze, 2000). However, only the latter type of research can provide detailed information on developmental trajectories, the timing and tempo of developmental change and inter-infant differences concerning this change. In this study, an intensive, longitudinal design was used. The intervals between measurements were kept short, because rapid development was expected during the measurement period. Using this design avoids the random variance that arises when different groups of infants are compared at different ages and allows studying and comparing the developmental trajectories of the two attentional mechanisms chosen as well as the interindividual variance of this development.

As described earlier, infants born prematurely are exposed to visual stimulation earlier in their development and, at the same time, have been shown to have an increased risk for later attentional problems. In early infancy both inferior as well as enhanced visual functioning has been described and theoretically underpinned. Further research on the early development of fundamental visual attentional mechanisms is needed. A third goal of this study was thus to compare the development of attention and gaze shifting observed in a group of healthy infants to the developmental trajectory found in a group of preterm infants.

Only in the recent years, a technique to measure eye movements in very young infants reliably and non-intrusively has become available. In order to describe scanning patterns properly, it is necessary to rest upon precise and solid data on shifts of gaze as well as locations of fixation points. Therefore, the current study makes use of the latest eye-tracking techniques.

Outline of the Dissertation

This thesis is divided into six chapters. Following this 1st introductory chapter, the development of visual scanning is addressed in Chapter 2. The eye movements and fixations while scanning a naturally moving face and a matched abstract stimulus are registered throughout the first few months of infancy. The development of attention and gaze shifting between the two types of stimuli is examined in Chapter 3. In Chapter 4, the association between the development of these skills – visual scanning and gaze shifting – is explored. While the Chapters 2, 3, and 4 are devoted to the development of full-term infants with no history of medical complications, Chapter 5 deals with the comparison of a group of preterm infants and a group of full-terms. Again, the development of gaze shifting between faces and abstract stimuli is analyzed. The last chapter, Chapter 6, presents summaries of the preceding chapters and ends with a discussion of the general conclusions to be drawn from this study, its limitations and its implications for further research.

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