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CHAPTER 10

The early development of visual attention and its implications for social and cognitive development

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Abstract: Looking behavior plays a crucial role in the daily life of an infant and forms the basis for cognitive and social development. The infant's visual attentional systems undergo rapid development during the first few months of life. During the last decennia, the study of visual attentional development in infants has received increasing interest. Several reliable measures to investigate the early development of attentional processes have been developed, and currently a number of new methods are giving fresh impetus to the field. Research on overt and covert as well as exogenously and endogenously controlled attention shifts is presented. The development of gaze shifts to peripheral targets, covert attention, and visual scanning behavior is treated. Whereas most attentional mechanisms in very young infants are thought to be mediated mainly by subcortical structures, cortical mechanisms become increasingly more functional throughout the first months. Different accounts of the neurophysiological underpinnings of attentional processes and their developmental changes are discussed. Finally, a number of studies investigating the implications of attentional development for early cognitive and social development are presented.

Keywords: visual attention; infant; covert attention; overt attention; orienting; disengagement; scanning; inhibition of return

Introduction

Anyone who has ever observed a few-weeks-old baby look around and examine his environment must have noticed how different his visual behavior is from that of an adult. A young infant tends to move his eyes in a slow and sluggish way, often it seems as if he does not notice interesting things in his peripheral visual field, and sometimes he appears just to gaze into space for long periods of time. The baby likes to look at patterns with high contrast, and from time to time his gaze appears to get "stuck" at an object or location. The infant may keep on staring there, although there may be other equally or more salient things to look at in his environment, for example a colorful toy or his mother's face. Were we to observe the same infant 3 or 4 months later, we would see that his looking behavior has changed dramatically. The infant now examines objects by scanning them quickly and systematically and tends to alternate intense inspections with brief looks away. His eye movements are fast, and he tracks moving objects or persons easily. He seems bright and alert, and complex, colorful, and moving stimuli attract his attention particularly easily.

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Vision plays a crucial role in the daily life of an infant. As young infants are unable to move around on their own or to reach for, grasp, and manipulate objects easily, they explore their environment and learn about the world mainly by looking. Looking is also one of the most important ways in which infants communicate with their caretakers. During face-to-face interaction, caretakers use their infant's looking behavior as an indicator of attention and adjust their communicative behavior accordingly (Papoušek and Papoušek, 1983). Early face-to-face interaction forms the beginning of social communication and also plays an important role in the development of social cognition.

Attentional processes in early childhood have attracted increasing interest from researchers during the last decades, and as a consequence, the early development of visual attention has become a fruitful field of study. In the early 1960s, infant looking measures were introduced to developmental psychology (see paragraph "Looking measures"), and since then, the study of infant attention has developed from a tool to investigate various aspects of early perceptual and cognitive development into a fully mature field in its own right. So, it has been stated recently that finally infant attention as a field of study has "grown up" (Colombo, 2002).

The research on the development of infant visual attention has produced a large body of well-established findings and well-reasoned models to explain them, and its progress has regularly been documented in review papers and books over the last years (see Atkinson, 2000; Johnson, S.P., 2001, Johnson, M.H., 2005a). To date, however, our knowledge of early attentional development is mainly based on experimental studies carried out in carefully controlled laboratory environments (but see Bornstein and Ludemann, 1989), and we have only very little precise information on young infants' visual and attentional behavior in more natural contexts and on how developmental changes in attentional behavior are connected to the infant's social-emotional and cognitive development.

Fortunately, in addition to attempts to understand the fundamental processes in infant attentional development, a functional view on infant attention is becoming increasingly important. Contextual effects on attentional processes are being studied, and the integration of early attentional development with findings on the development of early social-emotional processes and cognitive skills is receiving more and more attention (see Posner and Rothbart, 1980; Johnson, S.P., 2001; Colombo, 2002; Johnson, M.H., 2005b).

In addition, new research methods have given a special impetus to the field during the recent years. On the one hand, a number of new techniques have become available, particularly in the domain of measuring brain activity. On the other hand, established techniques for research with adults have been adapted and refined to make them suitable for the testing of infants.

This article has several goals. First of all, the most important methods to study infant attention and the advances made in this area will be reviewed. Then, an overview of recent findings on early attentional development will be provided and different accounts of the neurophysiological underpinnings of these developmental changes will be presented. Special attention will be paid to the recent progress made in understanding the intertwining of early attentional development and social-emotional and cognitive development.

Methods of studying the early development of attentional processes

Looking measures

Attention, vision, and human looking patterns have long fascinated researchers (see Bell, 1823; Müller, 1826), and also Wilhelm Preyer (1882), whose book *Die Seele des Kindes* (The Mind of the Child) is often considered as the beginning of infant psychology, describes his careful observations of the developmental changes in his infant son's visual behavior.

The simple observation of gaze was the earliest method of studying eye movements and visual attention, and still is very common (Hainline, 1993; Wade and Tatler, 2005). Two important paradigms in infant psychology are based on the observation of looking behavior: In the preferential looking paradigm infants are presented with two stimuli, and a reliably longer looking duration to one of them is interpreted as evidence that the infant discriminates the two displays (see Fantz, 1961; Fantz et al., 1962; also see Fig. 1). The other influential paradigm, the visual habituation procedure (and the familiarization method), is based on infants' tendency to look at novel rather than familiar stimuli and to show a decrement in looking time with continued exposure to the same stimulus. When after repeated exposure to one stimulus a novel one is presented, look duration to the unfamiliar stimulus will be longer if the infant discriminates the two stimuli (Bornstein, 1985). Both procedures have been extremely important in studying infants' developing vision (for a review see Kellman and Arterberry, 1998), and habituation-based methods have also widely been used to examine the early development of attentional and cognitive processes. However, overall looking measures are very unspecific and global, and the suitability of these methods particularly for the investigation of more complex

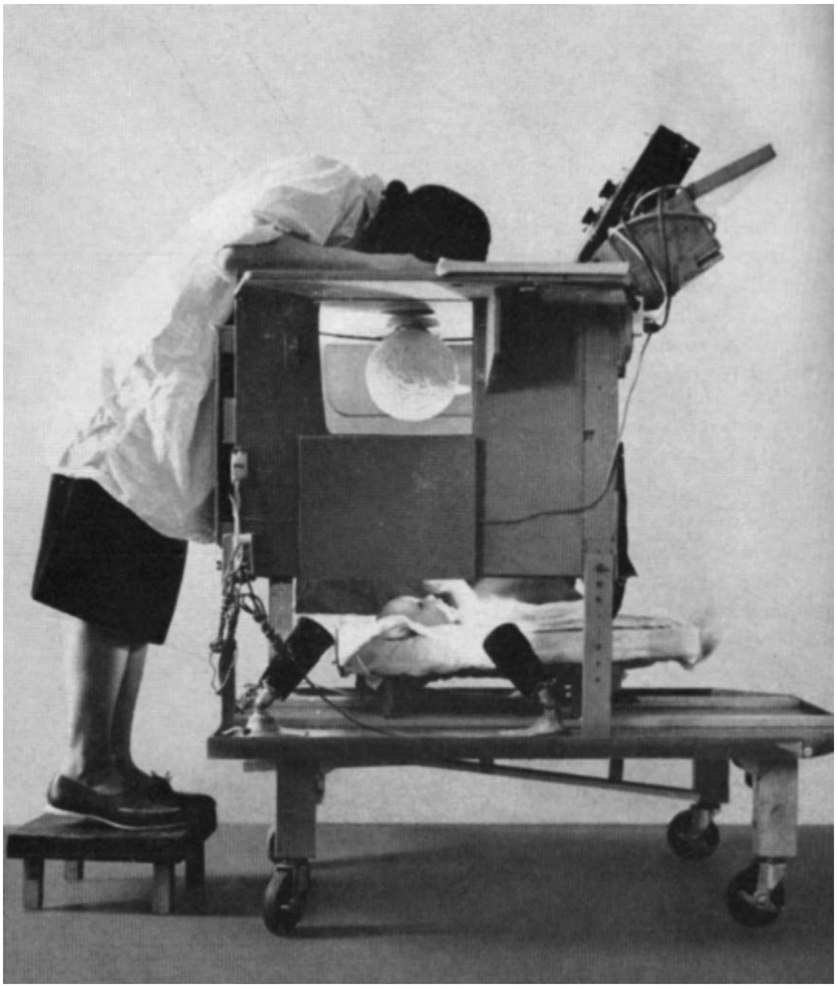

Fig. 1. Looking chamber used in Fantz' (1961) research on visual preferences in young infants. A human infant lies in a crib in the chamber, looking at objects hung from the ceiling. The observer, watching through a peephole, records the attention given to each object (copyright David Linton).

processes must be questioned (cf., Haith, 1998; Aslin and Fiser, 2005).

Measuring eye movements in infants

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 caused by the rotation of the eye. It was first used in the 1920s (Schott, 1922; Meyers, 1929), and is still applied frequently also in infant research (see Richards and Holley, 1999; Rosander and von Hofsten, 2004). However, the method has several limitations, especially when used with young infants (Finocchio et al., 1990; Aslin and McMurray, 2004). It can be sensitive to artifacts and it requires electrodes to be attached to the subject's face. Furthermore, EOG provides data only on the relative displacement of the eye and not on where 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. 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 are 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 (Harris et al., 1981; Bronson, 1983).

The technique of infrared corneal photography was first applied with human infants in the 1960s (Salapatek and Kessen, 1966; Haith, 1969) and has been improved in many respects since then (Aslin and McMurray, 2004; Haith, 2004; Hunnius and Geuze, 2004a). It has become substantially more accurate as a consequence of increased sampling rates and custom-built calibration procedures for infants. The new eye-tracking systems also allow a less restricted testing situation with less or no need to restrain the infant's head movements and minimal demands on the infant's postural control. Since very recently, 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, and this technique might provide a powerful tool for investigating perceptual and cognitive functions in infants (Hayhoe, 2004). Whereas overall looking measures offer, at best, global information about the processing of stimuli, infants' eye movement behavior can reveal more specific information about how infants encode complex visual stimuli, for example through measures of fixation locations, fixation durations, and the time of occurrence of fixation shifts or anticipatory eye movements (see Johnson et al., 2003; Falck-Ytter et al., 2006). This might help to extend our knowledge of young infants' visual behavior and the processes that underlie it, beyond what can be examined using habituation-based measures alone (Haith, 2004).

Heart rate measures

Heart rate (HR) is controlled directly by the autonomic nervous system, which is closely linked to the cerebral cortex where higher level cognitive processes, including attentional processes, are mediated. As a consequence of the connection between these systems, changes in HR measures occur in association with changes in attentional status and sensory and cognitive processing. HR measures, such as changes in cardiac cycle length or respiratory sinus arrhythmia, have therefore frequently been used to investigate attentional processes during visual tasks in adults (see Coles, 1972; Walker and Sandman, 1979) as well as in infants (for an overview, see Reynolds and Richards, in press). It has been proposed that changes in HR measures can serve as an index for attention phases during visual information processing (Graham, 1979; Porges, 1980; Richards, 1988; Richards and Hunter, 1998).

The HR-based differentiation between sustained attention, when an infant is focusing attention on an object or stimulus and is actively processing it, and attention termination, when the infant is still looking but is no longer encoding the stimulus (Richards and Casey, 1991), has made a particularly important contribution to our understanding of infants' attentional mechanisms and looking behavior during visual tasks (Finlay and Ivinskis, 1984; Richards, 1997, 2005b; Hicks and Richards, 1998; Richards and Holley, 1999; see paragraph ''The development of overt shifts of attention requiring disengagement'').

Marker tasks

Another way to study the development of attentional processes and to connect changes in performance to brain development is the use of marker tasks (Johnson, 2005a). This method uses behavioral tasks previously used in neurophysiological or brain imaging studies of adults or non-human primates whose neurological basis is thus relatively well established. Investigations of infants' performance on the same tasks at different ages and in various contexts provide insight into the interrelations between developmental changes in observable behavior and brain structures.

The marker task approach is frequently used to investigate neurodevelopmental models of infant visual attention (Atkinson and Braddick, 2003; Johnson, 2005a) and to determine whether behavioral observations are consistent with expectations derived from our current understanding of neurological development (see Clohessy et al., 1991; Hood, 1993; Hunnius et al., 2006b). However, the approach has been criticized as the same behavior might be mediated by different neurological structures at different stages of development (Goldman-Rakic, 1971). Comparisons between and generalizations across different groups of participants, such as infants, adults, and patients, should therefore be handled with care (Hood et al., 1998a). Further, the fact that the marker task approach focuses primarily on neurological underpinnings to explain performance without taking into account other variables such as endogenous states, has been commented on (Hainline, 1993).

Measures of brain activity

The technological progress of the last years has generated new methods for imaging brain activity in infants and has also refined the existing techniques. Many of the methods used with adults involve unpleasant procedures or the administration of radioactive substances (e.g., computed tomography or positron emission tomography (PET)), or are simply too complex and too sensitive to use with delicate subjects, who are indifferent to instructions (e.g., magnetoencephalography). However, a number of techniques can be used successfully with young children, and their application has pushed our insight into the neural underpinnings of attention and attentional development steadily further during the last decade (for an overview, see Thomas and Casey, 2003).

The classic technique of electro-encephalography (EEG; see Brazier, 1961) has been implemented in infants for many years (see Gibbs and Gibbs, 1941). In particular the use of event-related potentials (ERPs), or averaged electrophysiological responses to internal or external stimuli, has contributed greatly to our understanding of early attentional processes (see Csibra et al., 1998, 2001; Richards, 2001, 2005a).

Two relatively new methods, which are being used increasingly frequently in studies with young infants and are promising in the context of research on visual attention, are functional magnetic resonance imaging (fMRI) and near infrared spectroscopy (NIRS; see Meek et al., 1998; Dehaene-Lambertz et al., 2002; Taga et al., 2003; Csibra et al., 2004). Unlike EEG, which measures neural activity directly, these two techniques are based on the cerebral hemodynamic responses correlated with neural activity. The implementation of fMRI allows brain activity to be localized with a high degree of spatial precision. However, the technique has a limited time resolution, requires a very rigid constraint of the infant's head movements, and also exposes the infant to strong magnetic fields and to intense noise. NIRS is less sensitive to the infant's movements, but measurements might not be as precise as with fMRI. Although there are a number of practical issues still to be solved (see Aslin and Mehler, 2005), NIRS can be considered a powerful new approach to the study of the developing brain.

The new approaches offer interesting possibilities and perspectives for future research. However, obtaining evidence of where neural activity is located during a particular task is of limited scientific value on its own (and has been criticized as ‘‘neurophrenology’’ or ‘‘neophrenology’’, see Uttal, 2001; Aslin and Fiser, 2005). Only on the basis of strong theoretical and empirical foundations can brain imaging methods unfold their exciting potential (Hood, 2001).

Developmental changes in visual attention and eye movements

Visual orienting

Eye movements emerge during prenatal development (Prechtl, 1984). They have been observed around 16–18 weeks gestation, but are naturally not associated with visual stimulation before birth (although there might be some light reaching the fetus' eyes in utero). From the first days of their life, when awake and alert, infants selectively attend to different aspects of their visual environment. As newborns, for instance, they preferentially orient to and spend more time looking at a face-like pattern rather than a non-facelike stimulus (see Johnson et al., 1991a; Valenza et al., 1996) or a novel rather than a familiar stimulus (see Slater et al., 1988).

Shifts of gaze and shifts of attention are tightly associated, although they do not necessarily occur conjointly, and orienting — the aligning of attention with a source of sensory input — does not always have to be directly observable (Stelmach et al., 1997). Whereas eye movements that shift gaze from one location to another are named overt orienting, in covert orienting, foveation and visual attention do not coincide, and eyes, head, and body may remain stationary while attention shifts (Posner, 1980; Wright and Ward, 1998). In addition, shifts of attention — overt as well as covert — can be exogenously or endogenously generated. While exogenously controlled shifts of attention are automatic, as when infants orient to a salient stimulus appearing in their visual field, endogenously triggered orienting involves voluntary or strategic attention shifts to locations of interest (Jonides, 1980; Posner and Raichle, 1994). Scanning a visual display or following another person's gaze, for instance, might be primarily under endogenous control. These distinctions, which initially evolved from the literature on adult visual attention (Klein et al., 1992), have guided research on the development of visual orienting in infancy (see Fig. 2; cf., Johnson, 1994; Butcher and Kalverboer, 1997; Klein, 2005). In practice, however, the initiation of most attention shifts has both exogenous and endogenous components (Klein et al., 1992), and this of course also holds for infants' everyday attentional behavior.

Overt orienting to exogenous cues: the localization of stimuli in the peripheral visual field

Extensive research has been carried out to examine the development of reliable gaze shifting in

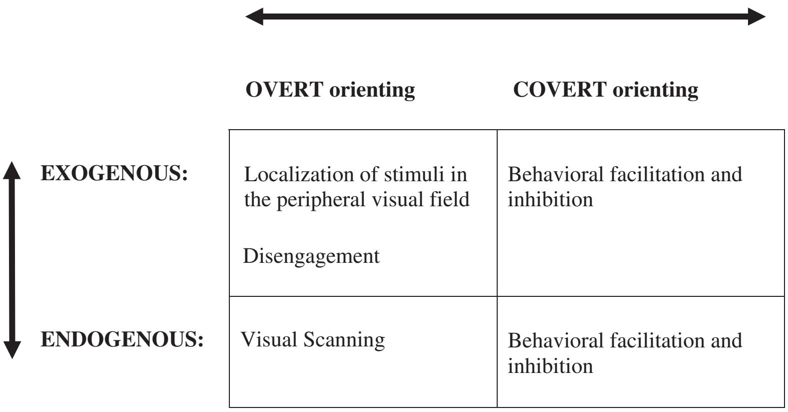

Fig. 2. Illustration of the distinction between overt versus covert orienting and exogenous versus endogenous control.

young infants and the factors that influence it (for reviews, see Mayer and Fulton, 1993; Maurer and Lewis, 1998). The sudden onset of a stimulus in the peripheral visual field triggers relatively automatic saccades, which accordingly have also been named ''visual grasp reflex'' (Rafal, 1998) or ''attention-getting'' mechanism (Cohen, 1972).

Infants as young as 1 month of age are able to localize a target, which appears in their peripheral visual field (Aslin and Salapatek, 1975; Lewis and Maurer, 1992), and this reaction has been shown to be present even at birth (Harris and MacFarlane, 1974; Lewis and Maurer, 1992). During the first months of life, overt orienting becomes steadily more efficient and infants look to a peripheral target more frequently and with shorter latencies (see Matsuzawa and Shimojo, 1997; Butcher et al., 2000). The structure of the eye movements has been described to change from a series of small movements even for targets at moderate eccentricity (Aslin and Salapatek, 1975; Salapatek et al., 1980; Richards and Hunter, 1997; Hunter and Richards, 2003; but cf., Hainline, 1993; Hainline et al., 1984) to the highly accurate, single large eye movement, possibly followed by one or two small corrective movements, characteristic of adults (Bartz, 1967; Weber and Daroff, 1971; Prablanc et al., 1978; Viviani and Swensson, 1982).

The eccentricity to which infants move their gaze to locate a target has been found to increase rapidly during the first 4 months of age (Harris and MacFarlane, 1974; Lewis and Maurer, 1992). Despite this fast early development, several studies report that an adult-like performance is not attained before the end of infancy (Dobson et al., 1998) or even the school-age years (Bowering et al., 1996; Tschopp et al., 1998).

A number of studies have demonstrated that the developmental course of the overt orienting response depends on the experimental setup and the specific characteristics of the triggering stimuli. In the usual experimental setup (see Fig. 3 for a schematic representation of the stimulus sequence in a gaze shifting task), simple physical characteristics of the peripheral target — such as its contrast, size, or luminance (Cohen, 1972; Lewis et al., 1985; Atkinson et al., 1992) — affect the probability and latency of its localization most strongly. Also when orienting is studied in a slightly more realistic laboratory situation, in which infants have to shift their gaze to stimuli surrounded by competing visual targets, stimulus salience mainly determines where infants look (Ross and Dannemiller, 1999; Dannemiller, 2002, 2005). More complex stimulus characteristics seem not to influence infants' simple gaze shifting (Hunnius and Geuze, 2004b), which is consistent with the automatic character of the orienting response.

The development of overt shifts of attention requiring disengagement

Being able to shift attention and gaze flexibly is a prerequisite for many behaviors, which play an important role in early development. Young infants explore and monitor their environment by looking from one location to another. They regulate the flow of visual input by alternating intense inspections of a stimulus with short looks away, and they control their arousal by regularly shifting their gaze away from an interaction partner (see paragraph ''Visual attention and early social-emotional development'').

However, when an infant is already 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. Whereas the ability to carry out a simple shift of gaze to a peripheral target has been shown to be functional around birth (see paragraph ''Overt orienting to exogenous cues: the localization of stimuli in the peripheral visual field''), infants between approximately 1 and 4 months of age have been reported to have difficulty looking away from a stimulus, once their attention has been engaged. As a consequence, they may exhibit long periods of staring. This phenomenon of difficulty with disengagement has been described frequently in the infant literature and has been referred to with such diverse terms as ''obligatory attention'' (Stechler and Latz, 1966), ''attention tropism'' (Caron et al., 1977), and ''sticky fixation'' (Hood, 1995). It can be observed in a

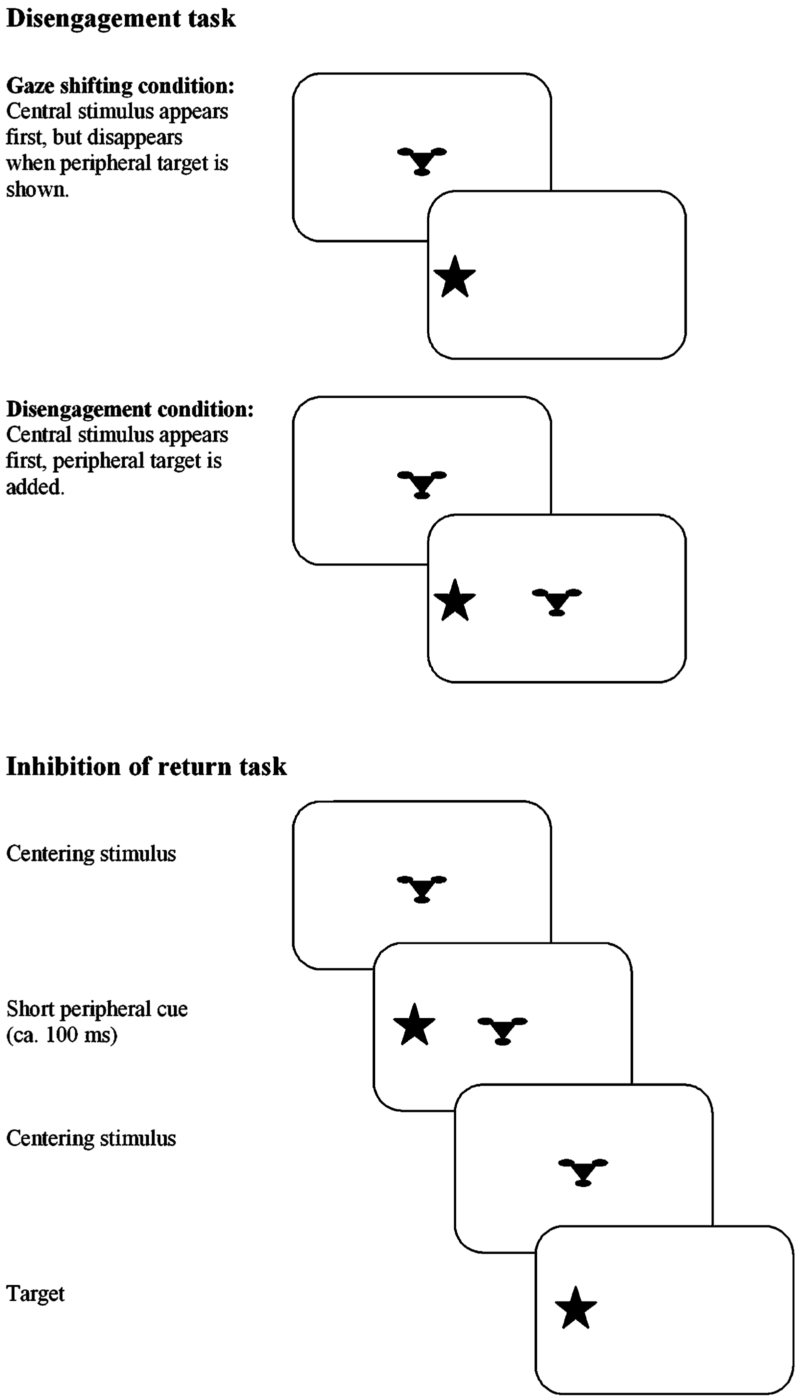

Fig. 3. Stimulus sequences in a disengagement task (simple gaze shifting versus disengagement) and in an IOR task.

laboratory context (see Fig. 3 for a schematic representation of the stimulus sequence in a disengagement task; Harris and MacFarlane, 1974; Aslin and Salapatek, 1975; but cf., Goldberg et al., 1997), in free looking situations (Stechler and Latz, 1966), or during social interaction (Hopkins and van Wulfften Palthe, 1985), and is also reported frequently by mothers and other caretakers as an everyday experience. From HR studies we know that infants are especially unlikely to shift their gaze to a target in the periphery when their attention is actively engaged by the central stimulus (Richards, 1997; Richards and Hunter, 1997; Hicks and Richards, 1998) and that they still detect and process peripheral stimuli, even when their gaze remains on the central stimulus (Finlay and Ivinskis, 1984).

It is not yet entirely clear whether and to what extent the stimulus competition effect is already present in newborns. A number of studies report that newborn infants respond to stimuli less far in the periphery when a central stimulus is present than when it is turned off (Harris and MacFarlane, 1974; MacFarlane et al., 1976), but findings on the latency of gaze shifts are mixed (Hood et al., 1996; Farroni et al., 1999).

Disengagement difficulties seem to increase between birth and 1 month of age (MacFarlane et al., 1976; Schwartz et al., 1987; Farroni et al., 1999) and are greatest in infants of 1–2 months (Johnson et al., 1991b; Hood and Atkinson, 1993; Butcher and Kalverboer, 1999). After 2 months, however, disengaging attention and shifting gaze away from a stimulus become increasingly efficient. By 4 months of age, infants are able to move their attention and gaze easily and rapidly, and staring behavior becomes rare (Hood and Atkinson, 1993; Butcher et al., 2000; Hunnius and Geuze, 2004b). From the age of approximately 6 months, infants' performance when shifting gaze between two stimuli is comparable to that of adults (Hood and Atkinson, 1993; Matsuzawa and Shimojo, 1997). Fixation shifts are faster in adults when two stimuli are presented successively than when they overlap (Saslow, 1967; Fischer and Weber, 1993), and it has been suggested that the phenomenon of obligatory attention is an extreme manifestation of this "gap effect" (Csibra et al., 1998; Hood et al., 1998a).

Infants' visual reactions in a disengagement experiment are modulated by the physical attributes of the stimuli used (Tronick, 1972; Finlay and Ivinskis, 1984; Butcher et al., 2000). Unlike the simple orienting response, the probability and latency of infants' shifts of gaze from a stimulus currently under attention to a target in the periphery are also influenced by higher order characteristics of the two stimuli (Hunnius and Geuze, 2004b). The degree of disengagement difficulty young infants might experience in daily life is therefore likely to vary between different situations.

Various explanations of disengagement difficulties in infants have been put forward. Some authors attribute staring behavior to young infants' inability to break off a fixation (Hood, 1995; Hood et al., 1996). Others argue that young infants have difficulty generating an eye movement while processing a stimulus that is currently in their central visual field (Johnson, 1990). Yet others (Rothbart et al., 1994) suggest that shifts of gaze are preceded by covert shifts of attention, and disengagement problems reflect difficulty shifting attention covertly.

A number of studies have addressed the implications of attentional development for young infants' gaze shifting in social situations. Hood et al. (1998b), for instance, showed that infants as young as 3 months of age are able to follow another person's gaze, if the experimental setup allows them to overcome their disengagement difficulties. The emergence of reliable disengagement corresponds with a change in the infant's looking behavior during natural face-to-face interaction. At this age, the infant starts to shift his gaze away more often during the interaction, either in order to regulate arousal (Stifter and Moyer, 1991) or to explore other locations that are becoming increasingly more interesting to them (Kaye and Fogel, 1980).

Covert orienting: facilitation and inhibition

As mentioned earlier, not all attention shifts occur overtly and together with an eye movement. The focus of attention can also be moved covertly while gaze is maintained at one location. Accordingly, the focus of attention has been compared to a beam of light that can be shifted between different locations independently from movements of the eyes (Posner et al., 1980; Eriksen and St. James, 1986). During fixation of a stimulus, rapid shifts of covert attention take place (Saarinen and Julesz, 1991) in order to select the next location to look at (Posner and Driver, 1992). Recently, it has been suggested that covert attention can also be directed to more than one location at a time, which supports a more complex model of covert attention than the metaphor of a unitary and indivisible attentional spotlight implies (see Hahn and Kramer, 1998; Awh and Pashler, 2000; McMains and Somers, 2004).

Covert shifts of attention to and away from a spatial location have been shown to affect subsequent responses to a target at this location (Posner, 1978). For approximately 300 ms, the perceptual processing of stimuli at the previously attended location is enhanced (Posner, 1980; Posner et al., 1985). If the interval between cue and target stimulus is longer than 300 ms, the response facilitation effect is reversed and the processing of targets in the vicinity of the cue is impaired (Posner and Cohen, 1984; Klein, 2005). This effect, which lasts for 2–3 s after the triggering event (Samuel and Kat, 2003), has been named inhibition of return (IOR; Posner et al., 1985).

In infants, the development of covert attention shifting has been studied by examining the emergence of response facilitation and IOR for cued targets. For this purpose, the spatial cuing paradigm initially developed by Posner (1980; Posner and Cohen, 1984) has been adapted for the use with infants (Hood, 1993; see Fig. 3 for a schematic representation of the stimulus sequence in an infant IOR task): While infants are looking at a central stimulus, a short peripheral cue is presented. As young infants are very unlikely to shift their gaze away from the central stimulus they are currently fixating (cf., paragraph "The development of overt shifts of attention requiring disengagement"), only a covert shift of attention can be carried out to the location of the cue. The central fixation stimulus subsequently disappears, and, following a delay, a target is presented either at the cued location or on the opposite side of the central fixation stimulus. The occurrence of facilitation or inhibition is then interpreted as evidence for the ability to shift attention covertly.

There is broad evidence that infants show facilitation of their reactions to a cued location after the age of 4 months (Hood and Atkinson, 1991; in Hood, 1995; Johnson et al., 1994) and possibly even from approximately 3 months on (Johnson and Tucker, 1996; Richards, 2000a; Richards, 2000b in Richards, 2005b). IOR after covert attention shifts, on the other hand, has been observed consistently only in infants of 4 months and older (Hood and Atkinson, 1991; Hood, 1995; Johnson, 1994; Johnson and Tucker, 1996; Butcher et al., 1999; but see Richards, 2000b in Richards, 2005b). Richards (2000a, 2001, 2005a) combined measures of infant looking behavior with ERPs to explore the development of covert attention and the hypothesized dissociation in the development of facilitation and IOR. The changes in the location of ERP activity he observed suggested a gradual development of the ability to shift attention covertly throughout the first months of infancy. Whereas infants of 3 months seem to show facilitation mainly as a result of automatic saccadic programming, infants from the age of 4 months might show both facilitation and IOR as a result of a shift of covert attention (Richards, 2000a).

At the same time, several studies have also demonstrated inhibition in much younger infants. After overt orienting to a cue, a few-days-old infants tended to look less frequently and more slowly in the direction of the preceding saccade (Valenza et al., 1994; Simion et al., 1995). These findings suggest that one of the mechanisms involved in overt IOR is already functional in neonates and is thus ready long before the ability to shift attention covertly emerges.

Interestingly, IOR, initially identified in terms of location-based coordinates, may also be defined in terms of object-based coordinates, and may move with objects (Tipper et al., 1991, 1994; Gibson and Egeth, 1994; Yi et al., 2003). It has been suggested that looking behavior is initially determined by environment-based IOR before object-based IOR starts to emerge (Harman et al., 1994).

By 8 months, cueing of a part of an object leads to IOR to the whole object, which shows that object-centered IOR is present by this age (Johnson and Gilmore, 1998). These mechanisms of location- and object-centered IOR are thought to play an important role in infants' growing ability to explore their environment in a functional and systematic way. It has been argued that IOR is an adaptive evolutionary mechanism that hinders attention from returning to a location where it has recently been engaged (either overtly or covertly), and thus biases orienting towards novel stimuli (Posner and Cohen, 1984).

During recent years, the significance of the covert visual attentional system in a social context has received increasing interest (see Butcher and Kalverboer, 1997). It has been shown that the processing of an object at which another person is looking is enhanced in adults as well as in infants (Friesen and Kingstone, 1998; Hood et al., 1998b; Driver et al., 1999). Such endogenously triggered shifts of covert attention by a person's eye direction can be elicited from infants as young as 3 months of age as indexed by frequencies of looks, saccadic latencies, and ERPs (Hood et al., 1998b; Farroni et al., 2003; Reid et al., 2004). It has been suggested that this attentional mechanism and the early sensitivity to other person's gaze direction provide the foundation for social interaction and particularly for the establishment of joint visual attention with a caregiver.

Visual scanning

Once very young infants have oriented to a stimulus, they scan it actively. However, their scanning patterns differ from those of older infants and adults. They tend to examine only limited parts of the stimulus (Haith, 1980; Bronson, 1990), to spend long periods fixating a few single locations (Salapatek, 1968; Bronson, 1996), and to ignore other stimuli in their visual field (Salapatek, 1975; Haith, 1980; Bronson, 1996). During the first weeks of life, infants have also been shown to look at the most salient features of a stimulus pattern, such as edges or outer contours, rather than (stationary) inner parts of a stimulus (''externality effect'', Salapatek, 1975; Milewski, 1976; ''contour salience effect'', Bronson, 1991).

From 2–3 months of age, infants start to explore a stimulus under examination more consistently and more extensively. They fixate more locations and various features, exhibit more brief fixations, and scan more rapidly over an array of stimulus figures (Salapatek and Kessen, 1966; Leahy, 1976; Bronson, 1982, 1990, 1994, 1996; Hunnius and Geuze, 2004a). Salient parts of a stimulus still attract the infants' gaze, but they have gained volitional, strategic control over their scanning behavior (Bronson, 1994). Bronson (1994) has described the developmental changes as a gradual transition from a non-flexible, infant-like way of scanning — characterized by extremely long fixations directed to single salient parts of a stimulus — to a more advanced, adult-like scanning mode with brief fixations and extensive fixation patterns.

Adults have been shown to adapt their scanning patterns to the stimuli they are exploring. Different scanning patterns have been reported for stimuli that differ in physical characteristics, such as luminance, texture, or color (von Wartburg et al., 2005), as well as in semantic aspects (Loftus and Mackworth, 1978; Henderson et al., 1999) or familiarity (Althoff and Cohen, 1999). Far less is known about the impact of stimulus characteristics on visual scanning in young infants. Recent research has provided evidence that young infants' ability to tailor their scanning behavior to the characteristics of the stimuli under examination evolves around 3 months of age (Johnson and Johnson, 2000; Hunnius and Geuze, 2004a). In their longitudinal study, Hunnius and Geuze (2004a) showed that, when exploring a complex, abstract stimulus in contrast to the well-known face of their mother, infants started to exhibit a scanning pattern with slightly longer fixation durations from the age of 14 weeks.

However, there are indications that some stimulus properties can influence the degree of maturity of scanning behavior during the first months of life. In infants of about 3 months of age, flickering stimuli have been shown to elicit less advanced scanning with more extremely long fixations around single prominent features compared to displays with continuous luminosity (Bronson, 1990), and it has been suggested that this also holds for complex moving, colorful stimuli compared to relatively simple, achromatic geometric forms (Johnson and Johnson, 2000; Hunnius and Geuze, 2004a). Before mature scanning behavior has become established, scanning patterns might be particularly susceptible to the characteristics of the stimuli.

As infants grow older, they attain increasing intentional control over their eye movements. By 4–5 months of age, they are able to examine their environment in an efficient and flexible way. They can shift gaze rapidly 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 and when familiar stimuli are scanned, recursive scanning patterns can be observed (Bronson, 1982). Most of these results on the development of scanning, however, stem from studies that examined infants' scanning of rather simple, abstract stimuli. How infants visually explore more natural stimuli, such as complex visual scenes, is largely unknown to date.

Faces are frequent stimuli in the world of an infant, and young infants' perception of faces has been studied extensively (see Simion et al., 2007/this issue; Pascalis and Slater, 2003). A number of studies have examined how infants explore facial stimuli and how their exploratory behaviors change as they grow older. It has been suggested that the limitations that have been found in young infants' scanning of abstract stimuli — such as the so-called externality effect — also hold for their visual exploration of faces. When infants younger than 2 months of age scan faces, they tend to restrict their fixations to the perimeter of the face, whereas infants older than 2–3 months are more likely to also inspect the internal facial features, especially the eyes and, to a much lesser extent, the mouth (Maurer and Salapatek, 1976; Haith et al., 1977; Hainline, 1978). One has to keep in mind, though, that the studies on which these results are based have used mostly photographs or drawings of faces (e.g., Hainline, 1978; Gallay et al., 2006), and when real faces were used, they were usually still faces (e.g., Maurer and Salapatek, 1976; Bronson, 1982). Only very few studies have examined infants' face scanning in more realistic interaction situations (but see Hunnius et al., 2007; Merin et al., 2007). When presented with a face that is talking and moving naturally, even infants as young as 6 weeks of age direct their gaze at the internal features of the face (Hunnius and Geuze, 2004a). Although their scanning patterns are indeed characterized by relatively few fixations, some of them extremely long, they spend most of the time looking at the eye and mouth region rather than the hairline or the perimeter of the face (see Fig. 4; Hunnius and Geuze, 2004a). This is in line with earlier findings that if the internal elements of a pattern are moving or flickering, they are more likely to be looked at even by very young infants (Bushnell, 1979; Girton, 1979).

The studies described imply that even very young infants are able to establish eye contact with their caregivers. Infants at risk for autism, however, show reduced looking at their mother's eyes during social interaction, but increased gaze at her mouth (Merin et al., 2007). From a very early age, healthy infants appear to be able to distinguish between faces with eyes directed at them and faces with averted gaze and to prefer those with eyes directed at them (Farroni et al., 2002; Hains and Muir, 1996). Mutual gaze plays a crucial role in the contact and communication between caregiver and infant, and is thought to be an important factor in the infant's social development and for the quality of the infant–caregiver relationship (Keller and Gauda, 1987; Schölmerich et al., 1995).

Neuropsychological background of visual attention and eye movements and its development

Neurophysiological background of eye movement generation

This overview of the early development of visual attention and eye movements raises the question which neurophysiological processes underlie the functions and developmental changes described above? The following two paragraphs are dedicated to this question.

Fig. 4. Example of a scan path of a 6-week-old infant while looking at a video of her mother's naturally moving face. Dots represent the location and duration of visual fixations.

One of the currently predominant models of eye movement generation is the one developed by Peter Schiller (Schiller, 1985, 1998). His most recent model (Schiller, 1998) is based on adult primate electrophysiological and lesion data and 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, whereas the posterior system is thought to generate fast, reactive eye movements and orienting responses.

The pathways of the anterior system, originating in retinal ganglion cells that are specialized for the analysis of fine detail and color (Richards and Hunter, 1998), project through the lateral geniculate nucleus to the striate cortex, and run — mainly through the temporal lobe — to the frontal eye fields. From there, 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, on the other hand, receives most of its input from retinal ganglion cells that are located in the peripheral retina and are specialized for the detection of sudden changes (Richards and Hunter, 1998). Its pathways project via the lateral geniculate nucleus to the striate cortex and then run, either directly or indirectly via the parietal lobe, through the basal ganglia to the superior colliculus.

Both systems, the anterior as well as the posterior eye movement systems, thus control the activity of the superior colliculus. Their excitatory or inhibitory input plays an important role in the generation of eye movements to interesting locations and at the same time in the inhibition of automatic eye movements in order to ensure the well-organized input of visual information.

Neuropsychological models of attentional development in infants

The visual and attentional behavior of an awake, alert infant is largely determined by the developmental status of the brain structures that form the visual system. Changes observed in behavior and its neural correlates can be due to maturation, but can as well occur as a response to experience (Greenough et al., 1987), and there are also several examples of neural and behavioral changes that are the result of an interaction between intrinsic factors and environmental aspects (Greenough et al., 1987; Johnson and Morton, 1991). Maturation therefore both lays the basis for experience (e.g., by influencing which visual features are salient at a particular age) and depends on experience because the neural processes, which produce structural change, are driven by input.

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

Gordon Bronson was one of the first to propose a model, which applied findings from research on adult neurological systems (e.g., Trevarthen, 1968; Schneider, 1969) to infant visual behavior (Bronson, 1974). According to Bronson's 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 the phylogenetically older visual system. It is only at 2–3 months of age that the locus of control switches to the primary visual system and its predominantly cortical pathways.

Bronson's original model, based on "two visual systems" (Schneider, 1969) and a subcortical–cortical dichotomy, has been criticized as being too simplistic and incomplete (Atkinson, 1984; Johnson, 1990). Further, the early presence of certain perceptual abilities, such as pattern recognition (Slater et al., 1983) or orientation discrimination (Atkinson et al., 1988), has given rise to the notion that there is at least some degree of cortically mediated visual processing at birth. It is now known that several comparatively independent cortical streams of visual processing exist (see Van Essen, 1985) and that they undergo rapid development during infancy, as a result of the generation and pruning of synapses, myelination, and neurotransmitter development (see de Haan and Johnson, 2003).

Bronson's latest model (Bronson, 1994, 1996) is based on the existence of 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 on 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 — salient areas close to fixation produce higher levels of 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, 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 spatial features 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.

Mark Johnson (1990, 1995a, 2005; Johnson et al., 1998) has similarly proposed a model of visual and attentional development that builds on Schiller's (1985) model of eye movement control, in particular on four distinct pathways Schiller describes — three cortical and one subcortical. Johnson argues that the characteristics of visually guided behavior mirror the degree of functionality of these four pathways and that the developmental state of the primary visual cortex determines which of these pathways is functional. In correspondence with the inside-out pattern of postnatal development in the cerebral cortex (see paragraph Nowakowski, 1987; Rakic, 1988), he hypothesizes that during early infancy the deeper layers of the cortex tend to be more active than more superficial ones. In newborn infants, only the deeper layers of the primary visual cortex are functional, and visually guided behavior is therefore controlled predominantly by the subcortical pathway.

The fast orienting response to abrupt changes in the peripheral visual field is generally thought to be mediated by subcortical structures (see Johnson, 1995a; Bronson, 1996; Atkinson and Braddick, 2003), notably the superior colliculus (Wurtz and Munoz, 1995). As mentioned above (see paragraph "Overt orienting to exogenous cues: the localization of stimuli in the peripheral visual field"), this simple orienting system, which is especially sensitive to movement, is thought to be relatively mature at birth. The stepwise saccades to peripheral targets observed in young infants and their disappearance during the first few months of life (Aslin and Salapatek, 1975; Richards and Hunter, 1997; Hunter and Richards, 2003), while poorly understood, may be evidence for the ongoing maturation of this system. Also IOR following overt orienting, which has been shown to be present already in newborn infants, is thought to be mediated mainly by subcortical structures, such as the superior colliculus (Valenza et al., 1994; Hood et al., 1998b).

Reliable gaze shifting away from stimuli currently under attention requires cortical control over the superior colliculus, and young infants have been shown to have trouble looking away from a salient stimulus (see paragraph "The development of overt shifts of attention requiring disengagement"). Johnson (1990, 1995a) has attributed the onset and decline of sticky fixation to the maturation of different cortical structures: During the first month, the nigral pathway, providing inhibitory input from the deeper layers of the primary visual cortex to the superior colliculus, becomes increasingly functional. This as yet unregulated tonic inhibition has as a temporary consequence the infant's disengagement difficulties. During the third and the fourth month, pathways through the parietal and frontal areas become functional, ending the tonic inhibition that initially caused the staring behavior and allowing the more differentiated regulation of collicular activity. Tests of an infant whose superior colliculus was intact but whose right cortex had been removed for the treatment of seizures showed sticky fixation after the age of 7 months to stimuli on the left side (Braddick et al., 1992). This supports the notion that modulation of the subcortical orienting system by cortical processes is necessary to end infants' disengagement difficulties. However, it does not confirm Johnson's (1990, 1995a) hypothesis that cortical inhibition of the superior colliculus is a prerequisite for the occurrence of sticky fixation. Other researchers have stressed the role of covert attentional mechanisms in disengagement, attributing the changes in infant orienting behavior to a network of brain structures, known as the "posterior attention system" (PAS; Posner and Petersen, 1990), including the posterior parietal lobe, the pulvinar nuclei of the thalamus, and the superior colliculus (see Johnson et al., 1991b; Rothbart et al., 1994). Studies investigating associations between infants' performance on disengagement and covert attention tasks, however, have been inconclusive on this issue (Johnson et al., 1991b; Butcher, 2000).

Whereas the subcortical components of the PAS, the superior colliculus and the pulvinar, appear to be functional around birth, the posterior parietal lobe is much less mature at birth, undergoing rapid development around 3–4 months of age (Conel, 1939–1967; Chugani et al., 1987; Chugani, 1994). Around this age, facilitation and IOR after covert orienting start to emerge (see paragraph "Covert orienting: facilitation and inhibition"). This is consistent with the view that developmental changes in areas of the PAS such as the parietal cortex play an important role in the ontogeny of covert attention (Johnson et al., 1994; Richards, 2005b).

At approximately the same age, but probably slightly earlier than reliable disengagement of attention emerges (Hunnius et al., 2006a), infants' scanning has improved substantially, having changed from mainly exogenously elicited reflexive to endogenously driven, volitional visual behavior (see paragraph "Visual scanning"). Whereas the phenomenon that young infants do not attend to a stationary pattern within a larger frame or pattern (externality effect) is characteristic of looking behavior that is controlled subcortically, purposive saccades are presumably mediated by a pathway extending to frontal structures, such as the frontal eye fields, that matures at approximately 3 months of age (Johnson, 1995a). The increasingly mature state of this parvocellular pathway is thought not only to lead to well-organized scanning behavior, but also to enhance anticipatory eye movements (Haith et al., 1988; Canfield and Haith, 1991; Csibra et al., 2001) and the inhibition of saccades (Johnson, 1995b).

Functional visual attention

Visual attention and early cognitive development

In an adult's life, attentional processes play an important role in many daily activities. Reading, recognizing a familiar face 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.

Several studies have tried to link early cognitive development and looking behavior. We know that attention patterns in early infancy are related to later cognitive functioning (Fagan and McGrath, 1981; Colombo, 1993) and that infants' looking duration during habituation shows continuity with cognition in later childhood (Rose et al., 1986; Bornstein, 1998). Furthermore, longer look durations are related to slower and more variable gaze shifting in a disengagement task (Frick et al., 1999), and it has been suggested that individual differences in the efficiency of disengagement of attention form the basis for the relationship between look duration and cognitive performance in infants (Colombo et al., 2001). Bronson (1991) compared scanning patterns of 12-week-old infants who were fast or slow in processing a stimulus, and showed that the infants who processed the stimulus more slowly also exhibited a less extensive scanning style characterized by frequent prolonged fixations (but cf., Krinsky-McHale, 1993). Differences in scanning patterns are also related to other perceptual and cognitive competences. In a recent study, Johnson et al. (2004) examined infants' ability to perceive object unity in a display of a moving rod partly occluded by a box and their scanning behavior. They showed that the scanning patterns of infants who appeared to perceive object unity were characterized by more fixations of longer duration on the relevant parts and the movement of the figure. Further research combining attentional and cognitive measures is needed and promising, as it might increase our understanding of how basic attentional and perceptual processes are connected to more complex cognitive skills.

Visual attention and early social-emotional development

The ability to shift attention and gaze swiftly and reliably plays a role not only in early cognitive development, but is also closely connected to the development of self-regulatory competences (Posner and Rothbart, 1981; Rueda et al., 2004; Rothbart et al., 2006). Looking away from a stimulus, which is annoying or too intense, is a way of regulating sensation, and it is therefore not surprising that sticky fixation has often been described as causing infants distress (Stechler and Latz, 1966; Tennes et al., 1972). Further, it is a daily observation of many mothers that they can relieve their fussy infant's distress by attracting his attention to something new or interesting, such as a toy, and the effectiveness of distraction as a soothing technique has also been demonstrated in a laboratory context (Harman et al., 1997).

A number of studies have addressed the associations between the development of attention and the development of emotion regulation. Infants' ease of disengagement in an experimental task was shown to be related to their level of distress when faced with limitations and to their soothability (Johnson et al., 1991b; McConnell and Bryson, 2005; but cf., Ruddy, 1993). Stifter and Braungart (1995) found that, orienting away (to the mother or an object) during a stressful situation was associated with a decrease in negative affect in 5-month-old infants. The ability to redirect attention away from distressing stimuli has similarly been shown to be related to lower levels of negative affect in infants of 13.5 months of age (Rothbart et al., 1992).

As mentioned before, early face-to-face interaction also calls on the infants' regulation skills. Infants shift their gaze regularly in order to regulate visual input and to avoid an unpleasant or too intense interaction (Cohn and Tronick, 1983; Stifter and Moyer, 1991; Hunnius et al., 2007). The still-face procedure (Tronick et al., 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. Several studies thus have provided support to the notion that attentional processes affect infants' regulatory skills and social behavior, and future research should continue to explore the interrelations of attentional and emotional development in infancy.

Abbreviations

EEG	electro-encephalography
EOG	electro-oculography
ERP	event-related potential
fMRI	functional magnetic resonance imaging
HR	heart rate
IOR	inhibition of return
ms	millisecond(s)
NIRS	near infrared spectroscopy
PAS	posterior attention system
PET	positron emission tomography

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References

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

Althoff, R.R. and Cohen, N.J. (1999) Eye-movement-based memory effect: a reprocessing effect in face perception. J. Exp. Psychol. Learn. Mem. Cogn., 25: 997–1010.

Aslin, R.N. and Fiser, J. (2005) Methodological challenges for understanding cognitive development in infants. Trends Cogn. Sci., 9: 92–98.

Aslin, R.N. and McMurray, B. (2004) Automated corneal-reflection eye-tracking in infancy: methodological developments and applications to cognition. Infancy, 6: 155–163.

Aslin, R.N. and Mehler, J. (2005) Near-infrared spectroscopy for functional studies of brain activity in human infants: promise, prospects, and challenges. J. Biomed. Opt., 10: 011009.

Aslin, R.N. and Salapatek, P. (1975) Saccadic localization of visual targets by the very young human infant. Percept. Psychophys., 17: 293–302.

Atkinson, J. (1984) Human visual development over the first six months of life. Hum. Neurobiol., 3: 61–74.

Atkinson, J. (2000) The Developing Visual Brain. Oxford Psychology Series 32. Oxford University Press, Oxford, UK.

Atkinson, J. and Braddick, O. (2003) Neurobiological models of normal and abnormal visual development. In: de Haan M. and Johnson M.H. (Eds.), The Cognitive Neuroscience of Development. Psychology Press, Hove, UK, pp. 43–71.

Atkinson, J., Hood, B.M., Wattam-Bell, J., Anker, S. and Tricklebank, J. (1988) Development of orientation discrimination in infancy. Perception, 17: 587–595.

Atkinson, J., Hood, B.M., Wattam-Bell, J. and Braddick, O. (1992) Changes in infants' ability to switch visual attention in the first three months of life. Perception, 21: 643–653.

Awh, E. and Pashler, H. (2000) Evidence for split attentional foci. J. Exp. Psychol. Hum. Percept. Perform., 26: 834–846.

Bartz, A.E. (1967) Fixation errors in eye movements to peripheral stimuli. J. Exp. Psychol., 75: 444–446.

Bell, C. (1823) On the motions of the eye, in illustration of the uses of the muscles and nerves of the orbit. Philos. Trans. R. Soc., 113: 166–186.

Bornstein, M.H. (1985) Habituation of attention as a measure of visual processing in human infants: summary, systematization, and synthesis. In: Gottlieb G. and Krasnegor N.A. (Eds.), Measurement of Audition and Vision in the First Year of Postnatal Life: A Methodological Overview. Ablex, Norwood, NJ, pp. 253–300.

Bornstein, M.H. (1998) Stability in mental development from early life: methods, measures, models, meanings, and myths. In: Simion F. and Butterworth G. (Eds.), The Development of Sensory, Motor and Cognitive Capacities in Early Infancy: From Perception to Cognition. Psychology Press, Hove, England, pp. 301–332.

Bornstein, M.H. and Ludemann, P.M. (1989) Habituation at home. Infant Behav. Dev., 12: 525–529.

Bowering, E.R., Maurer, D., Lewis, T.L., Brent, H.P. and Riedel, P. (1996) The visual field in childhood: normal development and the influence of deprivation. Dev. Cogn. Neurosci. Technical Report, No. 96.1.

Braddick, O., Atkinson, J., Hood, B., Harkness, W., Jackson, G. and Vargha-Khadem, F. (1992) Possible blindsight in infants lacking one cerebral hemisphere. Nature, 360: 461–463.

Brazier, M.A.B. (1961) A History of the Electrical Activity of the Brain: The First Half-Century. Macmillan, New York.

Bronson, G.W. (1974) The postnatal growth of visual capacity. Child Dev., 45: 873–890.

Bronson, G.W. (1982) The Scanning Patterns of Human Infants: Implications for Visual Learning. Monographs on Infancy No. 2. Ablex, Norwood, NJ.

Bronson, G.W. (1983) Potential sources of error when applying a corneal reflex eye-monitoring technique to infant subjects. Behav. Res. Methods Instrum., 15: 22–28.

Bronson, G.W. (1990) Changes in infants' visual scanning across the 2- to 14-week age period. J. Exp. Child Psychol., 49: 101–125.

Bronson, G.W. (1991) Infant differences in rate of visual encoding. Child Dev., 62: 44–54.

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

Bronson, G.W. (1996) The growth of visual capacity: evidence from infant scanning patterns. In: Rovee-Collier C. and Lipsitt L.P. (Eds.), Advances in Infancy Research, Vol. 11. Ablex, Norwood, NJ, pp. 109–141.

Bushnell, I.W.R. (1979) Modification of the externality effect in young infants. J. Exp. Child Psychol., 28: 211–229.

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. and Kalverboer, A.F. (1997) The early development of covert visuo-spatial attention and its impact on social looking. Early Dev. Parent., 6: 15–26.

Butcher, P.R. and Kalverboer, A.F. (1999) A phase transition in infants' ability to disengage visual attention. In: Savelsbergh G.J.P., van der Maas H.L.J. and van Geert P.L.C. (Eds.), Non-Linear Developmental processes. Royal Netherlands Academy of Arts and Sciences, Amsterdam, pp. 81–92.

Butcher, P.R., Kalverboer, A.F. and Geuze, R.H. (1999) Inhibition of return in very young infants: a longitudinal study. Infant Behav. Dev., 22: 303–319.

Butcher, P.R., Kalverboer, A.F. and 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 Behav. Dev., 23: 3–21.

Canfield, R.L. and Haith, M.M. (1991) Young infants' visual expectations for symmetric and asymmetric stimulus sequences. Dev. Psychol., 27: 198–208.

Caron, A., Caron, R., Minichiello, M.D., Weiss, S.J. and Friedman, S.L. (1977) Constraints on the use of the familiarization-novelty method in the assessment of infant discrimination. Child Dev., 48: 747–762.

Chugani, H.T. (1994) Development of regional brain glucose metabolism in relation to behavior and plasticity. In: Dawson G. and Fischer K. (Eds.), Human Behavior and the Developing Brain. Guilford, New York, pp. 153–175.

Chugani, H.T., Phelps, M.E. and Mazziotta, J.C. (1987) Positron emission tomography study of human brain functional development. Ann. Neurol., 22: 487–497.

Clohessy, A.B., Posner, M.I., Rothbart, M.K. and Vecera, S.P. (1991) The development of inhibition of return in early infancy. J. Cogn. Neurosci., 3: 345–350.

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

Cohn, J.F. and Tronick, E.Z. (1983) Three-month-old infants' reaction to simulated maternal depression. Child Dev., 54: 185–193.

Coles, M.G. (1972) Cardiac and respiratory activity during visual search. J. Exp. Psychol., 96: 371–379.

Colombo, J. (1993) Infant Cognition: Predicting Later Intellectual Functioning. Sage, Newbury Park, CA.

Colombo, J. (2002) Infant attention grows up: the emergence of a developmental cognitive neuroscience perspective. Curr. Direct. Psychol. Sci., 11: 196–199.

Colombo, J., Richman, W.A., Shaddy, D.J., Greenhoot, A.F. and Maikranz, J.M. (2001) Heart rate-defined phases of attention, look duration, and infant performance in the paired-comparison paradigm. Child Dev., 72: 1605–1616.

Conel, J.L. (1939–1967) The Postnatal Development of the Human Cerebral Cortex, Vol. 1–8. Harvard University Press, Cambridge, MA.

Csibra, G., Henty, J., Volein, A., Elwell, C., Tucker, L., Meek, J. and Johnson, M.H. (2004) Near infrared spectroscopy reveals neural activation during face perception in infants and adults. J. Pediatr. Neurol., 2: 85–89.

Csibra, G., Tucker, L.A. and Johnson, M.H. (1998) Neural correlates of saccade planning in infants: a high-density ERP study. Int. J. Psychophysiol., 29: 201–215.

Csibra, G., Tucker, L.A. and Johnson, M.H. (2001) Differential frontal cortex activation before anticipatory and reactive saccades in infants. Infancy, 2: 159–174.

Dannemiller, J.L. (2002) Relative color contrast drives competition in early exogenous orienting. Infancy, 3: 275–302.

Dannemiller, J.L. (2005) Evidence against a maximum response model of exogenous visual orienting during early infancy and support for a dimensional switching model. Dev. Sci., 8: 567–582.

Dehaene-Lambertz, G., Dehaene, S. and Hertz-Pannier, L. (2002) Functional neuroimaging of speech perception in infants. Science, 298: 2013–2015.

Dobson, V., Brown, A.M., Harvey, E.M. and Narter, D.B. (1998) Visual field extent in children 3.5–30 months of age tested with a double-arc LED perimeter. Vision Res., 38: 2743–2760.

Driver, J., Davis, G., Ricciardelli, P., Kidd, P., Maxwell, E. and Baron-Cohen, S. (1999) Gaze perception triggers reflexive visuospatial orienting. Vis. Cogn., 6: 509–540.

Eriksen, C.W. and St. James, J.D. (1986) Visual attention within and around the field of focal attention: a zoom lens model. Percept. Psychophys., 40: 225–240.

Fagan, J.F. and McGrath, S.K. (1981) Infant recognition memory and later intelligence. Intelligence, 5: 121–130.
Falck-Ytter, T., Gredebäck, G. and von Hofsten, C. (2006) Infants predict other people's action goals. Nat. Neurosci., 9: 878–879.
Fantz, R.L. (1961) The origin of form perception. Sci. Am., 204: 66–72.
Fantz, R.L., Ordy, J.M. and Udelf, M.S. (1962) Maturation and pattern vision in infants during the first six months. J. Comp. Physiol. Psychol., 55: 907–917.
Farroni, T., Csibra, G., Simion, F. and Johnson, M.H. (2002) Eye contact detection in humans from birth. Proc. Natl. Acad. Sci. U.S.A., 198: 9602–9605.
Farroni, T., Mansfield, E.M., Lai, C. and Johnson, M.H. (2003) Infants perceiving and acting on the eyes: tests of an evolutionary hypothesis. J. Exp. Child Psychol., 85: 199–212.
Farroni, T., Simion, F., Umiltà, C. and Dalla Barba, B. (1999) The gap effect in newborns. Dev. Sci., 2: 174–186.
Finlay, D. and 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. Dev. Psychol., 20: 29–36.
Finocchio, D.V., Preston, K.L. and Fuchs, A.F. (1990) Obtaining a quantitative measure of eye movements in human infants: a method of calibrating the electrooculogram. Vision Res., 30: 1119–1128.
Fischer, B. and Weber, H. (1993) Express saccades and visual attention. Behav. Brain Sci., 16: 553–610.
Frick, J.E., Colombo, J. and Saxon, T.E. (1999) Individual and developmental differences in disengagement of fixation in early infancy. Child Dev., 70: 537–548.
Friesen, C.K. and Kingstone, A. (1998) The eyes have it! Reflexive orienting is triggered by nonpredictive gaze. Psychon. Bull. Rev., 5: 490–495.
Gallay, M., Baudouin, J.-Y., Durand, K., Lemoine, C. and Lécuyer, R. (2006) Qualitative differences in the exploration of upright and upside-down faces in four-month-old infants: an eye-movement study. Child Dev., 77: 984–996.
Gibbs, F.A. and Gibbs, E.L. (1941) Atlas of Electroencephalography. Addison-Wesley, Cambridge, MA.
Gibson, B.S. and Egeth, H. (1994) Inhibition of return to object-based and environment-based locations. Percept. Psychophys., 55: 323–339.
Girton, M.R. (1979) Infants' attention to intrastimulus motion. J. Exp. Child Psychol., 28: 416–423.
Goldberg, M.C., Maurer, D. and Lewis, T.L. (1997) Influence of a central stimulus on infants' visual fields. Infant Behav. Dev., 20: 359–370.
Goldman-Rakic, P.S. (1971) Functional development of the prefrontal cortex in early life and the problem of neuronal plasticity. Exp. Neurol., 32: 366–387.
Graham, F.K. (1979) Distinguishing among orienting, defense, and startle reflexes. In: Kimmel H.D., van Olst E.H. and Orlebeke J.F. (Eds.), The Orienting Reflex in Humans. Lawrence Erlbaum, Hillsdale, NJ, pp. 137–167.
Greenough, W.T., Black, J.E. and Wallace, C.S. (1987) Experience and brain development. Child Dev., 58: 539–559.
de Haan, M. and Johnson, M.H. (2003) Mechanisms and theories of brain development. In: de Haan M. and Johnson M.H. (Eds.), The Cognitive Neuroscience of Development. Psychology Press, Hove, UK, pp. 1–18.
Hahn, S. and Kramer, A.F. (1998) Further evidence for the division of attention among non-contiguous locations. Vis. Cogn., 5: 217–256.
Hainline, L. (1978) Developmental changes in visual scanning of face and nonface patterns by infants. J. Exp. Child Psychol., 25: 90–115.
Hainline, L. (1993) Conjugate eye movements of infants. In: Simons K. (Ed.), Early Visual Development, Normal and Abnormal. Oxford University Press, New York, pp. 47–79.
Hainline, L., Turkel, J., Abramov, I., Lemerise, E. and Harris, C. (1984) Characteristics of saccades in human infants. Vision Res., 24: 1771–1780.
Hains, S.M.J. and Muir, D.W. (1996) Infant sensitivity to adult eye direction. Child Dev., 67: 1940–1951.
Haith, M.M. (1969) Infrared television recording and measurement of ocular behavior in the human infant. Am. Psychol., 24: 279–282.
Haith, M.M. (1980) Rules that Babies Look By. Lawrence Erlbaum, Hillsdale, NJ.
Haith, M.M. (1998) Who put the cog in infant cognition? Is rich interpretation too costly? Infant Behav. Dev., 21: 167–179.
Haith, M.M. (2004) Progress and standardization in eye movement work with human infants. Infancy, 6: 257–265.
Haith, M.M., Bergman, T. and Moore, M.J. (1977) Eye contact and face scanning in early infancy. Science, 198: 853–855.
Haith, M.M., Hazan, C. and Goodman, G.S. (1988) Expectation and anticipation of dynamic visual events by 3.5-month-old babies. Child Dev., 59: 467–479.
Harman, C., Posner, M.I., Rothbart, M.K. and Thomas-Thrapp, L. (1994) Development of orienting to locations and objects in human infants. Can. J. Exp. Psychol., 48: 301–318.
Harman, C., Rothbart, M.K. and Posner, M.I. (1997) Distress and attention interactions in early infancy. Motiv. Emot., 21: 27–43.
Harris, C.M., Hainline, L. and Abramov, I. (1981) A method for calibrating an eye-monitoring system for use with human infants. Behav. Res. Methods Instrum., 13: 11–20.
Harris, P. and MacFarlane, A. (1974) The growth of the effective visual field from birth to seven weeks. J. Exp. Child Psychol., 18: 340–348.
Hayhoe, M.M. (2004) Advances in relating eye movements and cognition. Infancy, 6: 267–274.
Henderson, J.M., Weeks, P.A. and Hollingworth, A. (1999) The effects of semantic consistency on eye movements during complex scene viewing. J. Exp. Psychol. Hum. Percept. Perform., 25: 210–228.
Hicks, J.M. and Richards, J.E. (1998) The effects of stimulus movement and attention on peripheral stimulus localization by 8- to 26-week-old infants. Infant Behav. Dev., 21: 571–589.
Hood, B.M. (1993) Inhibition of return produced by covert shifts of visual attention in 6-month-old infants. Infant Behav. Dev., 16: 245–254.

Hood, B.M. (1995) Shifts of visual attention in the human infant: a neuroscientific approach. In: Rovee-Collier C. and Lipsitt L.P. (Eds.), Advances in Infancy Research, Vol. 9. Ablex, Norwood, NJ, pp. 163–216.

Hood, B.M. (2001) Combined electrophysiological and behavioral measurement in developmental cognitive neuroscience: some cautionary notes. Infancy, 2: 213–217.

Hood, B.M. and Atkinson, J. (1991, March) Inhibition of return in 3-, 6-month-olds and adults. Paper presented at the Biennial Meeting of the Society for Research in Child Development. Seattle, WA, USA.

Hood, B.M. and Atkinson, J. (1993) Disengaging visual attention in the infant and adult. Infant Behav. Dev., 16: 405–422.

Hood, B.M., Atkinson, J. and Braddick, O.J. (1998a) Selection-for-action and the development of orienting and visual attention. In: Richards J.E. (Ed.), Cognitive Neuroscience of Attention: A Developmental Perspective. Lawrence Erlbaum, Mahwah, NJ, pp. 219–250.

Hood, B.M., Murray, L., King, F., Hooper, R., Atkinson, J. and Braddick, O. (1996) Habituation changes in early infancy: longitudinal measures from birth to 6 months. J. Reprod. Infant Psychol., 14: 177–185.

Hood, B.M., Willen, D.J. and Driver, J. (1998b) Adult's eyes trigger shifts of visual attention in human infants. Psychol. Sci., 9: 131–134.

Hopkins, B. and van Wulfften Palthe, T. (1985) Staring in infancy. Early Hum. Dev., 12: 261–267.

Hunnius, S. and Geuze, R.H. (2004a) Developmental changes in visual scanning of dynamic faces and abstract stimuli in infants: a longitudinal study. Infancy, 6: 231–255.

Hunnius, S. and Geuze, R.H. (2004b) Gaze shifting in infancy: a longitudinal study using dynamic faces and abstract stimuli. Infant Behav. Dev., 27: 397–416.

Hunnius, S., Geuze, R.H. and van Geert, P.L.C. (2006a) Associations between the developmental trajectories of visual scanning and disengagement of attention in infants. Infant Behav. Dev., 29: 108–125.

Hunnius, S., Geuze, R.H., Zweens, M.J. and Bos, A.F. (2006b) Effects of preterm experience on the developing visual system: a longitudinal study of shifts of attention and gaze in early infancy. Manuscript submitted for publication.

Hunnius, S., de Wit, T.C.J. and von Hofsten, C. (2007, May). Young infants' eye movements and scanning of faces during face-to-face interaction. Poster presented at the 37th Annual Meeting of the Jean Piaget Society, Amsterdam, The Netherlands.

Hunter, S.K. and Richards, J.E. (2003) Peripheral stimulus localization by 5- to 14-week old infants during phases of attention. Infancy, 4: 1–25.

Johnson, M.H. (1990) Cortical maturation and the development of visual attention in early infancy. J. Cogn. Neurosc., 2: 81–95.

Johnson, M.H. (1994) Visual attention and the control of eye movements in early infancy. In: Umiltà C. and Moscovitch M. (Eds.), Attention and Performance XV: Conscious and Nonconscious Information Processing. MIT Press, Cambridge, MA, pp. 291–310.

Johnson, M.H. (1995a) The development of visual attention: a cognitive neuroscience perspective. In: Gazzaniga M.S. (Ed.), The Cognitive Neurosciences. MIT Press, Cambridge, MA, pp. 735–747.

Johnson, M.H. (1995b) The inhibition of automatic saccades in early infancy. Dev. Psychobiol., 28: 281–291.

Johnson, M.H. (2005a) Developmental Cognitive Neuroscience: An introduction (2nd ed.). Blackwell Publishers, London.

Johnson, M.H. (2005b) The ontogeny of the social brain. In: Mayr U., Awh E. and Keele S.W. (Eds.), Developing Individuality in the Human Brain: A Tribute to Michael I. Posner. American Psychological Association, Washington, pp. 125–140.

Johnson, M.H., Dziurawiec, S., Ellis, H. and Morton, J. (1991a) Newborns' preferential tracking of face-like stimuli and its subsequent decline. Cognition, 40: 1–19.

Johnson, M.H. and Gilmore, R.O. (1998) Object-centered attention in 8-month-old infants. Dev. Sci., 1: 221–225.

Johnson, M.H., Gilmore, R.O. and Csibra, G. (1998) Toward a computational model of the development of saccade planning. In: Richards J.E. (Ed.), Cognitive Neuroscience of Attention: A Developmental Perspective. Lawrence Erlbaum, Mahwah, NJ, pp. 103–130.

Johnson, M.H. and Morton, J. (1991) Biology and cognitive development: The Case of Face Recognition. Blackwell, Oxford, UK.

Johnson, M.H., Posner, M.I. and Rothbart, M.K. (1991b) Components of visual orienting in early infancy: contingency learning, anticipatory looking, and disengaging. J. Cogn. Neurosci., 3: 335–344.

Johnson, M.H., Posner, M.I. and Rothbart, M.K. (1994) Facilitation of saccades toward a covertly attended location in early infancy. Psychol. Sci., 5: 90–93.

Johnson, M.H. and Tucker, L.A. (1996) The development and temporal dynamics of spatial orienting in infants. J. Exp. Child Psychol., 63: 171–188.

Johnson, S.P. (2001) Neurophysiological and psychophysical approaches to visual development. In: Kalverboer A.F., Gramsbergen A. (Series Eds.) and Hopkins J.B. (Section Ed.), Handbook of Brain and Behaviour in Human Development: IV. Development of perception and cognition. Elsevier, Amsterdam, pp. 653–675.

Johnson, S.P., Amso, D. and Slemmer, J.A. (2003) Development of object concepts in infancy: evidence for early learning in an eye tracking paradigm. Proc. Natl. Acad. Sci. U.S.A., 100: 10568–10573.

Johnson, S.P. and Johnson, K.L. (2000) Early perception-action coupling: eye movements and the development of object perception. Infant Behav. Dev., 23: 461–483.

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

Jonides, J. (1980) Towards a model of the mind's eye's movement. Can. J. Psychol., 34: 103–112.

Kaye, K. and Fogel, A. (1980) The temporal structure of face-to-face communication between mothers and infants. Dev. Psychol., 16: 454–464.

Keller, H. and Gauda, G. (1987) Eye contact in the first months of life and its developmental consequences. In: Rauh H. and Steinhausen H.-Ch. (Eds.), Advances in Psychology, No. 46. Psychobiology and Early Development. Elsevier, Amsterdam, pp. 129–143.

Kellman, P.J. and Arterberry, M.E. (1998) The Cradle of Knowledge: Development of Perception in Infancy. MIT Press, Cambridge, MA.

Klein, R.M. (2005) On the role of endogenous orienting in the inhibitory aftermath of exogenous orienting. In: Mayr U., Awh E. and Keele S.W. (Eds.), Developing Individuality in the Human Brain: A Tribute to Michael I. Posner. American Psychological Association, Washington, pp. 45–64.

Klein, R., Kingstone, A. and Pontefract, A. (1992) Orienting of visual attention. In: Rayner K. (Ed.), Eye Movements and Visual Cognition: Scene Perception and Reading. Springer, New York, pp. 46–65.

Krinsky-McHale, S. (1993, March) Visual scanning during information-processing in infancy. Poster presented at the Biennial Meeting of the Society for Research in Child Development. New Orleans, USA.

Leahy, R.L. (1976) Development of preferences and processes of visual scanning in the human infant during the first 3 months of life. Dev. Psychol., 12: 250–254.

Lewis, T.L. and Maurer, D. (1992) The development of the temporal and nasal visual fields during infancy. Vision Res., 32: 903–911.

Lewis, T.L., Maurer, D. and Blackburn, K. (1985) The development of young infants' ability to detect stimuli in the nasal visual field. Vision Res., 25: 943–950.

Loftus, G. and Mackworth, N.H. (1978) Cognitive determinants of fixation location during picture viewing. J. Exp. Psychol. Hum. Percept. Perform., 4: 565–572.

MacFarlane, A., Harris, P. and Barnes, I. (1976) Central and peripheral vision in early infancy. J. Exp. Child Psychol., 21: 532–538.

Matsuzawa, M. and Shimojo, S. (1997) Infants' fast saccades in the gap paradigm and development of visual attention. Infant Behav. Dev., 20: 449–455.

Maurer, D. and Lewis, T.L. (1998) Overt orienting toward peripheral stimuli: normal development and underlying mechanisms. In: Richards J.E. (Ed.), Cognitive Neuroscience of Attention: A Developmental Perspective. Lawrence Erlbaum, Mahwah, NJ, pp. 51–102.

Maurer, D. and Salapatek, P. (1976) Developmental changes in the scanning of faces by young infants. Child Dev., 47: 523–527.

Mayer, D.L. and Fulton, A.B. (1993) Development of the human visual field. In: Simons K. (Ed.), Early Visual Development, Normal and Abnormal. Oxford University Press, New York, pp. 117–129.

McConnell, B.A. and Bryson, S.E. (2005) Visual attention and temperament: developmental data from the first 6 months of life. Infant Behav. Dev., 28: 537–544.

McMains, S.A. and Somers, D.C. (2004) Multiple spotlights of attentional selection in human visual cortex. Neuron, 42: 677–686.

Meek, J.H., Firbank, M., Elwell, C.E., Atkinson, J., Braddick, O. and Wyatt, J.S. (1998) Regional hemodynamic responses to visual stimulation in awake infants. Pediatr. Res., 43: 840–843.

Merin, N., Young, G.Y., Ozonoff, S. and Rogers, S.J. (2007) Visual fixation patterns during reciprocal social interaction distinguish a subgroup of 6-month-old infants at-risk for autism from comparison infants. J. Autism Dev. Disord., 37: 108–121.

Meyers, I.L. (1929) Electronystagmography. A graphic study of the action currents in nystagmus. Arch. Neurol. Psychiatry, 21: 901–918.

Milewski, A. (1976) Infant's discrimination of internal and external pattern elements. J. Exp. Child Psychol., 22: 229–246.

Müller, J. (1826) Zur vergleichenden Physiologie des Gesichtssinnes des Menschen und der Thiere nebst einem Versuch über die Bewegungen der Augen und über den menschlichen Blick. C. Cnobloch, Leipzig, Germany.

Nowakowski, R.S. (1987) Basic concepts of CNS development. Child Dev., 58: 568–595.

Papoušek, H. and Papoušek, M. (1983) Biological basis of social interactions: implications of research for an understanding of behavioural deviance. J. Child Psychol. Psychiatry, 24: 117–129.

Pascalis, O. and Slater, A. (2003) The Development of Face Processing in Infancy and Early Childhood: Current Perspectives. Nova Science Publishers, New York.

Porges, S.W. (1980) Individual differences in attention: A possible physiological substrate. In: Keogh, B.K. (Ed.), Advances in Special Education, Vol. 2. JAI Press, Greenwich, CT, pp. 111–134.

Posner, M.I. (1978) Chronometric Explorations of Mind. Lawrence Erlbaum, Hillsdale, NJ.

Posner, M.I. (1980) Orienting of attention. Q. J. Exp. Psychol., 32: 3–25.

Posner, M.I. and Cohen, Y. (1984) Components of visual orienting. In: Bouma H. and Bouwhuis D.G. (Eds.), Attention and Performance X. Lawrence Erlbaum, Hillsdale, NJ, pp. 531–556.

Posner, M.I. and Driver, J. (1992) The neurobiology of selective attention. Curr. Opin. Neurobiol., 2: 165–169.

Posner, M.I. and Petersen, S.E. (1990) The attention system of the human brain. Annu. Rev. Neurosci., 13: 25–42.

Posner, M.I., Rafal, R.D., Choate, L.S. and Vaughan, J. (1985) Inhibition of return: neural basis and function. Cogn. Neuropsychol., 2: 211–228.

Posner, M.I. and Raichle, M.E. (1994) Images of Mind. Scientific American Books, New York.

Posner, M.I. and Rothbart, M.K. (1981) The development of attentional mechanisms. In: Howe H.E. and Flowers J.H. (Eds.), Nebraska Symposium on Motivation. University of Nebraska Press, Lincoln, NB, pp. 1–52.

Posner, M.I., Snyder, C.R. and Davidson, B.J. (1980) Attention and the detection of signals. J. Exp. Psychol., 109: 160–174.

Prablanc, C., Massé, D. and Echallier, J.F. (1978) Error-correcting mechanisms in large saccades. Vision Res., 18: 557–560.

Prechtl, H.F.R. (1984) Continuity and change in early neural development. In: Prechtl H.F.R. (Ed.), Continuity of Neural Functions from Prenatal to Postnatal Life. Clinics in Developmental Medicine, Vol. 94. Blackwell, Oxford, UK, pp. 1–15.

Preyer, W. (1882) Die Seele des Kindes. Beobachtungen über die geistige Entwicklung des Menschen in den ersten Lebensjahren. Th. Grieben's Verlag, Leipzig, Germany.

Rafal, R. (1998) The neurology of visual orienting: a pathological disintegration of development. In: Richards J.E. (Ed.), Cognitive Neuroscience of Attention: A Developmental Perspective. Lawrence Erlbaum, Mahwah, NJ, pp. 181–218.

Rakic, P. (1988) Specification of cerebral cortical area. Science, 241: 170–176.

Reid, V.M., Striano, T., Kaufman, J. and Johnson, M.H. (2004) Eye gaze cueing facilitates neural processing of objects in 4-month-old infants. Neuroreport, 15: 2553–2555.

Reynolds, G.D. and Richards, J.E. (in press) Infant heart rate: A developmental psychophysiological perspective. In: Schmidt L.A. and Segalowitz S.J. (Eds.), Developmental Psychophysiology. Cambridge University Press.

Richards, J.E. (1988) Heart rate changes and heart rate rhythms, and infant visual sustained attention. In: Ackles P.K., Jennings J.R. and Coles M.G.H. (Eds.), Advances in Psychophysiology, Vol. 3. JAI Press, Greenwich, CT, pp. 189–221.

Richards, J.E. (1997) Peripheral stimulus localization by infants: attention, age and individual differences in heart rate variability. J. Exp. Psychol. Hum. Percept. Perform., 23: 667–680.

Richards, J.E. (2000a) Localizing the development of covert attention in infants with scalp event-related potentials. Dev. Psychol., 36: 91–108.

Richards, J.E. (2000b) The development of covert attention to peripheral targets and its relation to attention to central visual stimuli. Paper presented at the International Conference on Infant Studies, Brighton, England.

Richards, J.E. (2001a) Cortical indexes of saccade planning following covert orienting in 20-week-old infants. Infancy, 2: 135–157.

Richards, J.E. (2005a) Localizing cortical sources of event-related potentials in infants' covert orienting. Dev. Sci., 8: 255–278.

Richards, J.E. (2005b) Development of covert orienting in young infants. In: Itti L., Rees G. and Tsotsos J.K. (Eds.), Neurobiology of Attention. Elsevier Academic Press, Amsterdam, pp. 82–88.

Richards, J.E. and Casey, B.J. (1991) Heart rate variability during attention phases in young infants. Psychophysiology, 28: 43–53.

Richards, J.E. and Holley, F.B. (1999) Infant attention and the development of smooth pursuit tracking. Dev. Psychol., 35: 856–867.

Richards, J.E. and Hunter, S.K. (1997) Peripheral stimulus localization by infants with eye and head movements during visual attention. Vision Res., 37: 3021–3035.

Richards, J.E. and Hunter, S.K. (1998) Attention and eye movement in young infants: neural control and development. In: Richards J.E. (Ed.), Cognitive Neuroscience of Attention: A Developmental Perspective. Lawrence Erlbaum, Hillsdale, NJ, pp. 131–162.

Rosander, K. and von Hofsten, C. (2004) Infants' emerging ability to represent occluded object motion. Cognition, 91: 1–22.

Rose, D.H., Slater, A. and Perry, H. (1986) Prediction of childhood intelligence from habituation in early infancy. Intelligence, 10: 251–263.

Ross, S.M. and Dannemiller, J.L. (1999) Color contrast, luminance contrast and competition within exogenous orienting in 3.5-month-old infants. Infant Behav. Devel., 22: 383–404.

Rothbart, M.K., Posner, M.I. and Kieras, J. (2006) Temperament, attention, and the development of self-regulation. In: McCartney K. and Phillips D. (Eds.), Blackwell Handbook of Early Childhood Development. Blackwell, Malden, MA, pp. 338–357.

Rothbart, M.K., Posner, M.I. and Rosicky, J. (1994) Orienting in normal and pathological development. Dev. Psychopathol., 6: 635–652.

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

Ruddy, M.G. (1993) Attention shifting and temperament at 5 months. Infant Behav. Dev., 16: 255–259.

Rueda, M.R., Posner, M.I. and Rothbart, M.K. (2004) Attentional control and self-regulation. In: Baumeister R.F. and Vohs K.D. (Eds.), Handbook of Self-Regulation: Research, Theory, and Applications. Guilford, New York, pp. 357–370.

Saarinen, J. and Julesz, B. (1991) The speed of attentional shifts in the visual field. Proc. Natl. Acad. Sci., 88: 1812–1814.

Salapatek, P. (1968) Visual scanning of geometric figures by the human newborn. J. Comp. Physiol. Psychol., 66: 247–258.

Salapatek, P. (1975) Pattern perception in early infancy. In: Cohen L.B. and Salapatek P. (Eds.), Infant Perception: From Sensation to Cognition, Vol. 1. Academic Press, New York, pp. 133–248.

Salapatek, P., Aslin, R.N., Simonson, J. and Pulos, E. (1980) Infant saccadic eye movements to visible and previously visible targets. Child Dev., 51: 1090–1094.

Salapatek, P. and Kessen, W. (1966) Visual scanning of triangles by the human newborn. J. Exp. Child Psychol., 3: 155–167.

Samuel, A.G. and Kat, D. (2003) Inhibition of return: a graphical meta-analysis of its time course and an empirical test of its temporal and spatial properties. Psychon. Bull. Rev., 10: 897–906.

Saslow, M.G. (1967) Latency for saccadic eye movement. J. Opt. Soc. Am., 57: 1030–1033.

Schiller, P. (1985) A model for the generation of visually guided saccadic eye movements. In: Rose D. and Dobson V.G. (Eds.), Models of the Visual Cortex. Wiley, Chichester, UK, pp. 62–70.

Schiller, P. (1998) The neural control of visually guided eye movements. In: Richards J.E. (Ed.), Cognitive Neuroscience of Attention. Lawrence Erlbaum, Mahwah, NJ, pp. 5–50.

Schneider, G.E. (1969) Two visual systems. Science, 163: 895–902.

Schölmerich, A., Leyendecker, B. and Keller, H. (1995) The study of early interaction in a contextual perspective: culture, communication, and eye contact. In: Valsiner J. (Ed.), Child Development within Culturally Structured Environments. Vol. III: Comparative-Cultural and Constructivist Perspectives. Ablex, Norwood, NJ, pp. 29–50.

Schott, E. (1922) Über die Registrierung des Nystagmus und anderer Augenbewegungen vermittels des Saitengalvanometers. Deutsches Archiv für Klinische Medizin, 140: 79–90.

Schwartz, T.L., Dobson, V., Sandstrom, D.J. and Van Hof-van Duin, J. (1987) Kinetic perimetry assessment of binocular visual field shape and size in young infants. Vision Res., 27: 2163–2175.

Simion, F., Leo, I., Turati, C., Valenza, E. and Dalla Barba, B. (2007) How face specialization emerges in the first months of life. Progr. Brain Res., 164: 169–185.

Simion, F., Valenza, E., Umiltà, C. and Dalla Barba, B. (1995) Inhibition of return in newborns is temporo-nasal asymmetrical. Infant Behav. Dev., 18: 189–194.

Slater, A., Morison, V. and Rose, D. (1983) Locus of habituation in the human newborn. Perception, 12: 593–598.

Slater, A., Morison, V. and Somers, M. (1988) Orientation discrimination and cortical function in the human newborn. Perception, 17: 597–602.

Stechler, G. and Latz, E. (1966) Some observations on attention and arousal in the human infant. J. Am. Acad. Child Psychol., 5: 517–525.

Stelmach, L.B., Campsall, J.M. and Herdman, C.M. (1997) Attentional and ocular movements. J. Exp. Psychol. Hum. Percept. Perform., 23: 823–844.

Stifter, C.A. and Braungart, J.M. (1995) The regulation of negative reactivity in infancy: function and development. Dev. Psychol., 31: 448–455.

Stifter, C.A. and Moyer, D. (1991) The regulation of positive affect: gaze aversion activity during mother-infant interaction. Infant Behav. Dev., 14: 111–123.

Taga, G., Asakawa, K., Maki, A., Konishi, Y. and Koizumi, H. (2003) Brain imaging in awake infants by near-infrared optical topography. Proc. Natl. Acad. Sci., 100: 10722–10727.

Tennes, K., Emde, R., Kisley, A. and Metcalf, D. (1972) The stimulus barrier in early infancy: an exploration of some formulations of John Benjamin. In: Holt R.R. and Peterfreund E. (Eds.), Psychoanalysis and Contemporary Science. Macmillan, New York, pp. 206–234.

Thomas, K.M. and Casey, B.J. (2003) Methods for imaging the developing brain. In: de Haan M. and Johnson M.H. (Eds.), The Cognitive Neuroscience of Development. Psychology Press, Hove, UK, pp. 19–41.

Tipper, S.P., Driver, J. and Weaver, B. (1991) Object-centred inhibition of return of visual attention. Q. J. Exp. Psychol. A, 43: 289–298.

Tipper, S.P., Weaver, B., Jerreat, L.M. and Burak, A.L. (1994) Object-based and environment-based inhibition of return of visual attention. J. Exp. Psychol. Hum. Percept. Perform., 20: 478–499.

Trevarthen, C.B. (1968) Two mechanisms of vision in primates. Psychol. Forsch., 31: 299–337.

Tronick, E. (1972) Stimulus control and the growth of the infant's effective visual field. Percept. Psychophys., 11: 373–376.

Tronick, E.Z., Als, H., Adamson, L., Wise, S. and Brazelton, T.B. (1978) The infant's response to entrapment between contradictory messages in face-to-face interaction. J. Am. Acad. Child Psychol., 17: 1–13.

Tschopp, C., Safran, A.B., Viviani, P., Reicherts, M., Bullinger, A. and Mermoud, C. (1998) Automated visual field examination in children aged 5–8 years. Part II: normative values. Vision Res., 38: 2211–2218.

Uttal, W.R. (2001) The New Phrenology: The Limits of Localizing Cognitive Processes in the Brain. MIT Press, Cambridge, MA.

Valenza, E., Simion, F., Cassia, V.M. and Umiltà, C. (1996) Face preference at birth. J. Exp. Psychol. Hum. Percept. Perform., 22: 892–903.

Valenza, E., Simion, F. and Umiltà, C. (1994) Inhibition of return in newborn infants. Infant Behav. Dev., 17: 293–302.

Van Essen, D.C. (1985) Functional organization of primate visual cortex. In: Peters A. and Jones E.G. (Eds.), Cerebral Cortex, Vol. 3. Plenum, New York, pp. 259–329.

Viviani, P. and Swensson, R.G. (1982) Saccadic eye movements to peripherally discriminated visual targets. J. Exp. Psychol. Hum. Percept. Perform., 8: 113–126.

Wade, N.J. and Tatler, B.W. (2005) The Moving Tablet of the Eye: The Origins of Modern Eye Movement Research. Oxford University Press, New York.

Walker, B.B. and Sandman, C.A. (1979) Human visual evoked responses are related to heart rate. J. Comp. Physiol. Psychol., 93: 717–729.

von Wartburg, R., Ouerhani, N., Pflugshaupt, T., Nyffeler, T., Wurtz, P., Hügli, H. and Müri, R.M. (2005) The influence of colour on oculomotor behaviour during image perception. Neuroreport, 16: 1557–1560.

Weber, R.B. and Daroff, R.B. (1971) The metrics of horizontal saccadic eye movements in normal humans. Vision Res., 11: 921–928.

Wright, R.D. and Ward, L.M. (1998) The control of visual attention. In: Wright R.D. (Ed.), Visual Attention. Oxford University Press, New York, pp. 132–186.

Wurtz, R. and Munoz, D. (1995) Role of monkey superior colliculus in control of saccades and fixation. In: Gazzaniga M.S. (Ed.), The Cognitive Neurosciences. MIT Press, Cambridge, MA, pp. 533–548.

Yi, D.-J., Kim, M.-S. and Chun, M.M. (2003) Inhibition of return to occluded objects. Percept. Psychophys., 65: 1222–1230.