3. NEUROBIOCORCAL MODELS OF VIEWA DEVELOPMENT

CHAPTER FOUR

The development of visual attention and the brain

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INTRODUCTION

Attention shows development throughout the lifespan. In the early period of infancy, attention is directed primarily to salient characteristics of the environment and, by 2 or 3 years of age, comes under subject-directed control. The attention system comes under control of the child's executive functioning and is used in the service of cognitive, social, and emotional tasks. Some aspects of attention show gradual development over the entire period of childhood and adolescence, and then follow the course of other cognitive changes in the adult period. Many of these changes in attention are based upon age-related changes in brain areas involved in attention.

This chapter presents a neurodevelopmental perspective on the development of visual attention, focusing on research done with infants and very young children, because of the wealth of studies showing brain-attention relations in this age range. The primary focus is on visual attention, again because of the broad set of theories and empirical studies in this area. However, the comments about infants and young children should generalize to other ages, and the comments about visual attention should generalize to other sensory systems. First, two influential neurodevelopmental models of visual attention that relate the development of visual attention to changes in the brain are reviewed; a recent model that relates a general arousal/attention system to the development of visual attention is also presented. Second, three research areas that illustrate the role that brain development plays in the changes that occur in infant attention are examined. These areas will show the role that developmental change in a general attention/arousal system has on infant recognition memory, developmental changes in covert orienting and attention and their relation to brain development, and saccade planning. Some implications of the role of brain development in visual attention are discussed.

NEURODEVELOPMENTAL MODELS OF VISUAL ATTENTION

Two influential models that relate the development of visual behaviour in young infants to concurrent changes in the brain are Bronson's "two visual systems" (1974, 1997) and Johnson's model emphasizing the role of the primary visual cortex (1990, 1995; Johnson, Gilmore, & Csibra, 1998; Johnson, Posner, & Rothbart, 1991). Bronson was the first to take a specific hypothesis about neural systems developed in adult and animal studies and apply it to infant visual behaviour. His model was well received and many research studies interpreted their results in light of his model. Johnson took an established model of eye movement control (Schiller, 1985) and knowledge of the development of the primary visual area and presented a model that showed how infant visual behaviour was governed by changes in neural systems. Johnson's model and similar models have generated a wide body of behavioural, psychophysiological, and neuropsychological research in infants and young children. Although both neurodevelopmental models were concerned with a variety of visual behaviour, I use these models in this chapter in their application to visual attention. Also, in this section I present a model I have been using to guide my research that relates developmental changes in a general attention/arousal system to visual attention development.

Bronson's two visual systems.

The most influential theory of developmental change in visual behaviour controlled by brain development is that of Gordon Bronson (1974, 1997; see also Karmel & Maisel, 1975; Maurer & Lewis, 1979; Salapatek, 1975). Bronson's theory postulated two systems in the brain (e.g. Schneider, 1969) that control visual behaviour. The primary visual system has excellent visual acuity and is devoted to fine pattern visual analysis. The secondary visual system has poor visual acuity and responds to stimulus location and movement. It is dedicated to the detection and localization of targets in the periphery. The primary visual system is over-represented in the fovea and primary visual cortex and the secondary system is represented equally across the retina and in other areas of the brain involved in visual behaviour (e.g. the superior colliculus). According to Bronson, the secondary visual system is phylogenetically older and exists relatively mature at birth. Thus, newborn infant visual behaviour should respond primarily to movement, stimulus location, and peripheral visual information, but not to fine visual detail. The cortical components of the primary visual system show major developmental changes from 1 to 2 months of age until well into the second year. Thus, sensitivity to fine visual detail, attention to forms and objects, and memory for patterns should begin about 2 months of age and increase rapidly from 2 to 12 months. According to this model, the development of the brain areas involved in vision is directly responsible for changes in the infant's visual behaviour and visual attention.

Bronson's neurodevelopmental model of infant visual behaviour explained the findings of many studies on infant visual attention. The propensity of newborn infants to be extremely sensitive to motion and peripheral visual stimuli, and the later onset of detailed pattern discrimination, were consistent with this model. The model distinguished correctly between the control of peripheral orienting by subcortical neural systems, and visual attention involved in infant recognition memory and attention controlled by higher cortical visual systems. It captured to some extent the development patterns of those systems. However, the model was too simplistic. Several brain systems control visual behaviour. These systems, and the subsystems and brain areas involved in them, show developmental changes such as myelination, synaptic generation, neural innervation, synaptic pruning, and neurotransmitter development (see Chapter 1). Many specifics of the "two visual systems" (Schneider, 1969) are now held to be incorrect or incomplete in explaining the role of the brain in visual behaviour and visual attention.

Johnson's development of primary visual area (V1)

Several models from the 1990s relate development in the brain areas controlling visual behaviour to developmental changes in infant and child visual behaviour. The prototype of these models is that developed by Mark Johnson (Johnson, 1990, 1995; Johnson et al., 1991, 1998). Johnson posits that development in the layers of the primary visual cortex acts as a limiting factor for visual behaviour and visual attention controlled by brain systems. Johnson uses Schiller's (1985, 1998) model of the neural pathways for short-latency reflex saccades, smooth pursuit eye movements, attention-directed saccades, and inhibitory relations between attention-directed and reflexive eye movements. The short-latency reflex saccade pathway is primarily subcortical and mature at birth. The other pathways each have connections in various layers of the primary visual cortex before projecting to other cortical areas (e.g. area MT for smooth pursuit eye movements; areas MT, parietal cortex, frontal eye fields for attention-directed saccades). Specific developmental changes in the layers of the primary cortex from birth to about 6 months act as a gateway for the onset of these eye movements in young infants. Figure 4.1 shows the changes in the primary visual cortex that act as the gateway for these neural pathways. The changes in the primary visual cortex are posited to be responsible for the dates of the onset of smooth pursuit eye movement, "sticky fixation", attention-directed saccades, and other infant visual behaviour.

Johnson's model has been influential in generating research on visual attention in infants and young children and on other neurodevelopmental models of infant visual attention (see Chapter 3; also Hood, 1995; Hood, Atkinson, & Braddick, 1998; Maurer & Lewis, 1998; Richards, 2000a; Richards & Casey, 1992; Richards & Hunter, 1998). This model explains the general phenomena explained by Bronson's model of the early sensitivity to peripheral stimuli and later sensitivity



Figure 4.1. Developmental changes in the layers of the primary visual cortex and the connections to areas of the brain controlling eye movement. From Johnson (1995). M = magnocellular; P = parvocellular; LGN = lateral geniculate nucleus; SC = superior colliculus; BG = basal ganglia; MT = medial temporal.

to fine visual detail, object and form, and recognition memory. It also explains several other developmental changes (e.g. smooth pursuit initiation, "sticky fixation", attention-directed eye movements) and makes predictions about visual behaviour and visual attention in the young infant and into early childhood. Some of the details of the model are in dispute (see Richards & Hunter, 1998) and the interpretation of the role of the frontal cortex in saccade planning has been questioned (Canfield, Smith, Brezsnyak, & Snow, 1997; Smith & Canfield, 1998; Wentworth & Haith, 1998; Wentworth, Haith, & Karrer, 2001). None the less, Johnson's neurodevelopmental model and similar models have been influential in explaining the role of the brain in the development of visual attention and visual behaviour.

The development of general arousal/attention

In several places (Berg & Richards, 1997; Richards, 2000a; Richards & Casey, 1992; Richards & Hunter, 1998), I have presented a model where infants' heart rate changes during stimulus presentation are used to distinguish phases of attention. Recently, this model was explicated as showing the relation between the development of a general arousal/attention system in the brain and brain systems







Plate 2. A topographical mapping of the Nc component that occurs during sustained attention and inattention for the 4.5-, 6-, and 7.5-month-old infants (from Richards, 2000c).



Plate 3. Equivalent current dipole analysis of the presaccadic ERP potential occurring at 50ms before a target in an expected location. The equivalent current dipole (bottom) generated a scalp topographical potential map (top right) that matched the recorded ERP (top left).



Plate 4. The hippocampus, along with surrounding cortical structures (including subiculum, presubiculum, parasubiculum, entorhinal cortex, perirhinal and parahippocampal cortices. From Brain, Mind, and Behavior by Floyd Bloom, Charles A. Nelson, and Arlyne Lazerson © 1985, 1988, 2001 by Educational Broadcasting Corporation. Used with the permission of Worth Publishers, with permission.



Plate 5. The basal ganglia, which consists primarily of the striatum (caudate nucleus and putamen) and the globus pallidus. From Brain, Mind, and Behavior by Floyd Bloom, Charles A. Nelson, and Arlyne Lazerson © 1985, 1988, 2001 by Educational Broadcasting Corporation. Used with the permission of Worth Publishers.



Plate 6. Prefrontal cortex, in particular, the dorsolateral and orbitofrontal cortices. From Brain, Mind, and Behavior by Floyd Bloom, Charles A. Nelson, and Arlyne Lazerson © 1985, 1988, 2001 by Educational Broadcasting Corporation. Used with the permission of Worth Publishers.



Plate 7. Top: Schematic view of auditory cortex in a squirrel monkey demonstrating tonotopic map. Microelectrode recordings were made in each tile and the characteristic frequency determined. Bottom: A superimposed map of response latency. Each strip of characteristic frequency responds at a range of latencies. Superimposed maps are characteristic of sensory cortex in all modalities (adapted with permission from Cheung et al., 2001, © American Physiological Society).



Plate 8. Left: Visual cortex is composed of columns of cells responsive to lines of different orientation (see colour code at right). In normal developing cats, a dramatic sharpening of the borders occurs between postnatal (P) days 21 and 33. In cats whose eyes have been sutured shut, the orientation columns develop normally until P26 and then their responses deteriorate rapidly. Patterned stimulation is only necessary for maintenance, not for formation, of the orientation columns (reprinted with permission from Crair et al. (1998). Science, 279, p.566. Copyright 1998 American Association for the Advancement of Science).

involved in specific cognitive activities (Richards, 2000a). One aspect of attention is the arousal associated with energized cognitive activity. This arousal is associated with increased performance on cognitive tasks and the sustaining of performance over extended periods of time. This arousal system is based upon neuroanatomical connections between the mesencephalic reticular activity system and the cortex (Heilman, Watson, Valenstein, & Goldberg, 1987; Mesulam, 1983; see Fig. 1 in Richards, 2000a). It probably uses the noradrenergic and cholinergic neurotransmitter systems (Robbins & Everitt, 1995; see Fig. 2 in Richards, 2000a) to heighten arousal and increase attentive cognitive performance. The heart rate changes occurring during infant attention index this general arousal/attention system and thus provide an indirect measure of the brain areas controlling sustained attention.

There are three interesting aspects of this arousal system for the present chapter. First, it affects a wide range of modalities, sensory systems, cognitive systems, and cognitive processes. Thus its energizing aspect could affect visual attention or attention to other stimulus modalities. This general system might influence a specific system in the brain that has selective properties, so that this arousal could be accompanied by modality-specific attentive behaviour (e.g. stimulus modality effects on the blink reflex; Richards, 1998, 2000b). In this case, the "arousal" system might actually inhibit modalities or cognitive processes that interfere with the specific cognitive processes currently engaged. Second, there are dramatic developmental changes in this arousal system at least through the first year of life. This is seen, for example, by a change in the level of the heart rate response during attention (Richards, 1989), changes in the effect of this system on selective attention systems (Richards, 1998), and changes in the effect of this system on brain responses during attention (Richards, 2000c). The effect of the development of this system will be discussed in the next section. Third, this model is complementary, rather than competitive, to models such as those of Johnson or Bronson. Richards (2000a) distinguished between the general arousal/attention system and its development, and the development of specific attention systems. The Johnson model, for example, was concerned primarily with the development of several systems involved in eye movement control and visual behaviour. Such specific systems develop concurrently with this general system to influence infant visual attention (see eye movement studies by Richards & Holley, 1999). A full treatment of the effects of brain development on visual attention in infants and children must deal with many brain areas and cognitive systems.

Measuring "neuro" in neurodevelopmental models

One weakness in the neurodevelopmental models of visual attention is the lack of direct measures of brain activity in developing human infants. The most common manner in which neurodevelopmental models are tested is with the "marker task".

These are behavioural tasks for which brain areas have been well specified using animal, invasive, or neuropsychological preparations. Johnson (1997) proposes that such tasks can be used with infants and young children. Developmental change in the behaviour on the tasks is inferred to represent developmental changes in the brain area controlling their functioning. This indirect method allows inferences to be made about brain development without the concomitant invasive measurement techniques used in animals, adults, or with neuropsychological patients. However, careful theoretical and empirical links must be made between the brain system and cognitive behaviours for this approach to work. In several examples (see the sections "Covert orienting and attention" and "Saccade planning") it can be shown that this method can be deceptive in its claims supporting neurodevelopmental models of visual attention.

An approach that provides a more direct measurement of brain function is the use of psychophysiological measures (see Chapter 2). Two measures of brain activity have been used that are derived from electrical potential activity occurring on the scalp: the electroencephalogram (EEG) and scalp-recorded event-related potentials (ERPs). The electrical activity occurring on the scalp consists of changing electrical voltages that are caused by action potentials summed over large numbers of neurons, synapses, neural pathways, and neural systems. The spontaneous electrical activity occurring on the scalp, the EEG, has been used as a measure of arousal during task performance (Bell, 1998; Ray, 1990) and is thought to reflect the underlying cognitive processes occurring in the brain related to task performance. However, EEG activity is difficult to link to specific cortical areas and attempts to do so require theoretical linkages (neural generators, skull and scalp conductance, electrical changes on the scalp; see Chapter 2). It has been rarely used in studies of attention development.

Scalp-recorded electrical activity can be related to specific experimental events or cognitive processes. The resulting ERPs might provide a non-invasive and direct measure of functioning within specific brain areas (Hillyard, Mangun, Woldroff, & Luck, 1995). ERPs are derived by averaging EEG changes over multiple experimental (or cognitive) events. The averaging process eliminates or attenuates the spontaneous activity in the EEG and results in electrical potential changes related to specific events. The ERP has varying positive and negative electrical waves that are referred to as "components". These components are hypothesized to be controlled by specific neural areas and psychological processes (Hillyard et al., 1995; Swick, Kutas, & Neville, 1994). Current methods using high-density EEG recording (Tucker, 1993; Tucker et al., 1994) and cortical source localization (Huizenga & Molenaar, 1994; Nunez, 1990; Scherg, 1990; Scherg & Picton, 1991) can be used with ERP to identify cortical areas involved in cognitive processes (see the section "Saccade planning"). Cortical source localization analysis allows the ERP to be used as a direct measure of the cortical areas involved in cognitive processes and experiment events (Richards, 2000c; see Chapter 2 for further discussion of localization of the sources of

ERP components). This chapter emphasizes areas of study in which the measurement of the ERP in infants and children help to confirm the neurodevelopmental models of visual attention.

Not all psychophysiological measures are so direct. For example, I have used heart rate changes during visual attention in infants and preschool children as a measure of the general arousal system (see studies in Richards, 2000a). As with behavioural marker tasks, the relation between the neural system governing arousal/attention (Heilman et al., 1987; Mesulam, 1983) and heart rate control are well known. Yet, it is only the theoretical and empirical linkages found in animal studies or invasive studies with other populations that allow the inferences to be made when using this measure in infants. In this respect, heart rate is a "behavioural marker task" similar to eye movements, reaction time, novelty preference, or habituation. Several other psychophysiological measures have the same indirect measurement status as do heart rate and behavioural tasks—e.g. electromyogram (EMG; Richards, 1998); electro-oculogram (EOG; Richards & Hunter, 1997).

AROUSAL/ATTENTION SYSTEM AND RECOGNITION MEMORY

This section reviews studies showing how the general arousal/attention system affects the development of infant recognition memory. As in the previous section, I have used changes in infant heart rate during stimulus presentation to distinguish phases of infant attention (Richards, 2000a; Richards & Casey, 1992; Richards & Hunter, 1998). These phases are the automatic interrupt, stimulus orienting, sustained attention, and attention termination. These attention phases differ in the type of behaviour and cognitive processes that occur and in heart rate changes that occur when they are in effect. Figure 4.2 depicts the heart rate changes occurring during these phases of attention and Table 4.1 has a list of some of the cognitive processes occurring in these phases. For example, stimulus orienting is a period at the beginning of stimulus processing when the infant evaluates stimulus novelty and decides whether to allocate further mental resources to the stimulus. It is characterized by a rapid deceleration of heart rate and lasts 1-5s. Sustained attention maintains the level of information processing initiated in stimulus orienting and continues processing the stimulus. This phase of attention is quite variable. It can be quite short (2-3s) or long (60-120s), depending on the state of the infant, the complexity of visual information in the stimulus, and individual differences between infants. Heart rate during this phase continues at a lower level than during prestimulus levels. Finally, during attention termination the heart rate returns to its prestimulus level. During this phase the infant does not process information in the stimulus and the sensitivity to any new stimulus can be attenuated.



Figure 4.2. Average heart rate change as a function of stimulus presentation following stimulus onset for the heart rate defined attention phases for infants from 3 to 6 months of age (from Richards & Casey, 1991, Heart rate variability during attention phases in young infants. *Psychophysiology*, 28, 43–53. Cambridge University Press, 1991 © The Society for Psychophysiological Research. Reprinted with permission.)

TABLE 4.1.

Heart rate and behaviour/cognitive processes in heart-rate-defined attention phases (see full description in Richards & Casey, 1992)

Phase	Heart rate change	Behaviour and cognitive processes
Automatic interrupt	Biphasic heart rate change Deceleration–acceleration < 1s duration	Detect transient change in environment Startle reflex Automatically engaged
Stimulus orienting	Large heart rate deceleration 1–5s duration	Evaluate stimulus novelty Process preliminary information Make decision to suspend processing, or continue extended processing
Sustained attention	Heart rate below prestimulus Variable duration	Detailed information processing Subject-controlled Developmental and individual differences occur
Attention termination	Heart rate return to prestimulus level 5–7s duration	No information processing Insensitivity to new stimulation "Refractory period"

Of primary interest to this chapter are the phases of sustained attention, attention termination, and the time after attention termination but before attention is re-engaged. The heart rate slows down and remains below the prestimulus level during sustained attention (see Fig. 4.2). During this time the infant is engaged in subject-controlled processing of stimulus information. This phase of attention represents the energizing of cognitive processes, i.e. the arousal phase of the general arousal/attention system (Richards, 2000a). Alternatively, during the attention termination phase the heart rate has returned to its prestimulus level. Infants can continue to direct fixation towards the stimulus for periods of time without a re-engagement of attention. These periods represent inattentiveness, and the infant is not processing stimulus information. This represents the lack of arousal of the arousal/attention system in the brain (Richards, 2000a). There are several reviews of the relation between these heart rate changes and infant and child behaviour (Berg & Richards, 1997; Richards, 1995, 2000a; Richards & Casey, 1992; Richards & Hunter, 1998; Richards & Lansink, 1998).

The relation between the heart-rate-defined attention phases and infant recognition memory has been shown in three studies using "behavioural markers" of infant recognition memory. Two studies have shown that a familiarization stimulus presented for only 5 or 6s results in recognition memory (Frick & Richards, 1999; Richards, 1997). In these studies, we presented 3- to 6-month-old infants with a Sesame Street film that elicited sustained attention (heart rate slowing in Fig. 4.2). A familiarization stimulus was then presented for 5 or 6s followed by the Sesame Street film. On "no exposure" trials the Sesame Street film was played continuously. Then, about 10s later, the paired-comparison procedure (Fagan, 1974) was used to test for a preference for the novel stimulus that would indicate recognition memory for the familiarized pattern. The infants looked longer at the novel stimulus in the test phase on the 5s or 6s exposure trials than on noexposure trials. In fact, the infants looked at the novel stimulus on these 5s or 6s exposure trials for as long as they did on control trials with a traditional 20s exposure trial. These results imply that the acquisition of stimulus information by young infants occurs primarily when the infant is in a highly aroused state, i.e. sustained attention. We have also shown that infants distribute their fixations to the novel and familiar stimuli in the test phase of the paired-comparison task depending on their attention state (Richards & Casey, 1990). Novelty preference (fixation on the novel stimulus) occurred primarily during sustained attention, whereas no preference (fixation equally likely on novel or familiar stimulus) occurred during attention termination.

Recently, we have begun to study how developmental changes in the arousal/ attention system affect infant recognition memory using direct measures of brain activity (Richards, 2000c). This study uses a common procedure in which brief visual stimuli are presented in an "oddball" procedure (Courchesne, 1977, 1978; Nelson & Collins, 1991, 1992; see reviews by Nelson, 1994, 2000, Nelson & Dukette, 1998). This procedure consists of the presentation of one stimulus relatively frequently and an "oddball" stimulus that is presented relatively infrequently. We

use Nelson's modification of the procedure to familiarize the infant with these two stimuli ("frequent familiar", "infrequent familiar") before the brief presentations and to present a series of novel stimuli relatively infrequently ("infrequent novel") during the brief presentations.

The ERP is used as a direct measure of brain activity in the procedure. The ERP has components such as the P1 (or "P100"), N1, P2, N2, P3 (or "P300"), and various slow waves that differ for adult and infant participants (see Nelson, 1994; Nelson & Monk, 2000; Nelson & Dukette, 1998 or de Haan & Nelson, 1997, for a review of these components). The studies of the recognition of briefly presented visual stimuli find two types of components in this task. First, there is a large negative component occurring about 400–800ms after stimulus onset. This negative component is primarily located in the central leads and has been labelled the Nc ("Negative central"; Courchesne, 1977, 1978; Courchesne, Ganz, & Norcia, 1981). In most studies, the Nc component is larger to the infrequently presented stimuli and has been hypothesized to represent a general attentive or alerting to the presence of a novel stimulus. However, if the frequently presented and infrequently presented stimuli are already familiar to the infant, the Nc component does not differ (Nelson & Collins, 1991, 1992).

The second type of ERP activity found in these studies are slow waves occurring from 800 to 1500ms after stimulus presentation. Negative slow waves are found in response to the infrequent novel stimuli and positive slow waves are found in response to the infrequent familiar stimuli. Thus, infants are sensitive to novelty *per se* and to the frequency of the stimulus presentation. At the youngest testing ages (about 4 months), these later waves do not differ but by 6 months of age (Nelson & Collins, 1991) or 8 or 12 months (Nelson & Collins, 1992; Nelson & deRegnier, 1992) these three stimulus presentation procedures result in differing ERP potential shifts.

The results of the study I am conducting show that attention to the visual stimuli enhances the Nc component (Richards, 2000c). Infants at 4.5, 6, or 7.5 months of age have been tested in this study. Sustained attention is elicited in the infants with a Sesame Street film and the brief visual stimuli are overlaid upon the movie during sustained attention or during inattentive periods. Figure 4.3 shows the ERP changes from the 10-20 recording montage for the frequent familiar, infrequent familiar, and infrequent novel stimuli. The Nc component occurring 400-700ms after stimulus presentation can be seen clearly in these graphs. This component is approximately equivalent for the three presentation procedures. Plate 1 shows topographical potential maps of the Nc for the three presentation methods during attentive and inattentive periods. The response during attention is a widespread negative response in the central area of the scalp for the three presentation methods. The response during inattention is weaker or absent. There is a difference in the breadth of the response for the two infrequent conditions and the frequent condition, whereas the amplitude of the response is the same. The similarity between these three topographical maps suggests that the Nc response is an



Figure 4.3. The ERP in response to the frequent familiar, infrequent familiar and infrequent novel presentations for 4- to 7.5-month-old infants. These recordings are from the 10–20 electrodes (+Oz). The Nc component occurs 400–700 ms after stimulus onset and the slow waves occur 800–1500ms after stimulus presentation (from Richards, 2000c).

orienting response that is greater during attention but is not closely related to stimulus novelty or recognition memory. The Nc response is larger when the general arousal system is energized ("sustained attention") than when the arousal system is not active ("inattention").

This study also shows developmental changes in the Nc component consistent with the development of the general arousal/attention system, and shows some effect of attention on the slow wave components. Plate 2 shows the changes over the three testing ages for the Nc response for attentive and inattentive periods. There was a clear increase in the amplitude of the Nc component during attentive periods over the three testing ages. The response during the inattentive periods changed only slightly. This finding is consistent with the model that the general arousal/attention system continues developing into the second half of the first year. There was some effect of attention on the late slow waves. In general, this difference consisted of larger slow waves during attention than inattention, but primarily for the oldest ages in the study. The youngest ages showed inconsistent patterns for the slow wave activity.

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These studies show that the arousal aspect of sustained attention invigorates the acquisition of stimulus information (Richards, 1997; Frick & Richards, 2001) and the exhibition of recognition memory (Richards, 2000c; Richards & Casey, 1990). The study using the ERP measures has two broad implications. First, it implies that the Nc component is a manifestation of the general arousal/attention system of the brain. This interpretation suggests that such an ERP measure might provide a direct measure of this brain system, complementing heart rate, which is an indirect measure of this general arousal/attention system. Second, this study shows the interaction between the general attention system and a specific system supporting recognition memory. The enhancement of the slow waves during sustained attention demonstrates how the general system invigorates specific brain areas occurring during recognition memory. The facilitative effect of sustained attention on infant recognition memory (Frick & Richards, 2001; Richards, 1997) could occur because specific brain areas responsible for information acquisition or recognition are enhanced during sustained attention.

COVERT ORIENTING AND ATTENTION

One aspect of infant attention that has been studied with direct measures of brain activity is covert orienting and attention. Shifts of visual attention can occur without moving the eyes to a new location-"covert attention". Covert orienting of attention implies that attention and eye movements are partially independent, and that information can be processed in peripheral locations when the eyes remain fixed in a central location. The spatial cueing procedure developed by Posner (Posner, 1980; Posner & Cohen, 1984) can be used to measure covert orienting and attention. The participant's fixation is held at a central location and a peripheral cue and target are presented. If the target follows the cue in the same location at very short intervals, the response to the target is faster than if the cue and target are in a different location, i.e. facilitation. Alternatively, if the cue and target are separated by longer intervals the response to the target is slower in the cued location than in other locations, i.e. inhibition of return. Facilitation and inhibition of return are behavioural indices that attention was shifted to the cued location in the absence of specific eye movements. Hood (1993, 1995; Hood & Atkinson, 1991) developed a version of this task appropriate for infant participants. Figure 4.4 is a schematic illustration of the procedure used for infant participants (adapted from Hood, 1995; used in Richards, 2000d,e, 2001a,b). The spatial cueing procedure used with infant participants presents a central stimulus that engages fixation in the centre location and then presents a cue simultaneous with the central stimulus, followed by a delay, and then presents the target without the central stimulus.

Studies of covert orienting in young infants find that infants do not show consistent facilitation until about 4 to 6 months of age, but the results are not entirely consistent across studies. Hood and Atkinson (1991, reported in Hood, 1995)





used the spatial cueing procedure shown in Fig. 4.4 with 100 or 600 ms cuetarget asynchronies. The 3-month-old infants showed no evidence of facilitation of a saccade to the target at either delay interval. Conversely, Richards (2000d, e), using this paradigm, did find facilitation of the reaction time of the saccade towards the target for 3-month-old infants at short cue-target delay asynchronies. Similarly, a study by Butcher and colleagues using bilateral targets found that, from about 6 to 16 weeks of age infants would look more frequently and faster to the cued target location than to an uncued location (Butcher, Kalverboer, & Geuze, 1999). A similar study by Johnson and Tucker (Johnson & Tucker, 1996) did not find such effects with 2-month-old infants. However, by 4 or 6 months of age, nearly all studies report that at short cue-target delays a saccade to the cued side occurs faster than a saccade to an uncued or neutral location (Hood, 1993, 1995; Hood & Atkinson, 1991; Johnson, Posner, & Rothbart, 1991; Johnson & Tucker, 1996; Richards, 2000d,e, 2001a).

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Almost no studies find inhibition of return after covert shifts of attention in the first 3 months, and some studies have reported inhibition of return around 4 months of age. Infants show inhibition of return following overt localization shifts from the newborn age. That is, if an overt fixation shifts from a central location to a peripheral location and then back to the central location, there is a lower probability of shifting back to the same location in the presence of bilateral targets and the shifts to that same location take longer to occur (Simion, Valenza, Umilta, & Barba, 1995; Valenza, Simion, & Umilta, 1994; however, see also Clohessy, Posner, Rothbart, & Vecera, 1991). In the spatial cueing procedure where an overt shift of fixation does not occur, infants at 2 and 3 months of age do not show inhibition of return, whereas infants at 4 months of age and beyond do (Butcher et al., 1999; Clohessy et al., 1991; Hood, 1993, 1995; Hood & Atkinson, 1991; Johnson et al., 1991; Johnson & Tucker, 1996; Richards, 2000d,e, 2001a). These findings imply that the mechanism for inhibiting the return of attention to the recently attended location might exist at birth but that the infants do not show covert shifts of attention in the spatial cueing procedure that would result in facilitation or inhibition of return.

Facilitation and inhibition of return in the spatial cueing paradigm have been explained in neurophysiological terms by those studying adults and those studying infants. Inhibition of return is thought to be mediated by the superior colliculus (Rafal, 1998). Overt fixation shifts, or merely planning to make an eye movement, activate pathways in the superior colliculus and inhibition of return results after that activation. The neurodevelopmental approach would approve this explanation, because the pathways governing eye movements that involve the superior colliculus are mature at birth (Hood, 1993, 1995; Johnson, 1990, 1995; Richards & Hunter, 1998; Simion et al., 1995; Valenza et al., 1994). Thus, newborn infants should and do show inhibition of return after overt eye movements. Covert orienting or covert shifting of attention can result in inhibition of return when the participant shifts attention, activates the pathways of the superior colliculus, but inhibits the final motor pathway for the saccade. Such enhancement and inhibition is hypothesized to be controlled by a "posterior attention network" (Posner, 1995; Posner & Petersen, 1990). This network includes the parietal cortex, regions of the thalamus projecting to the parietal cortex (e.g. pulvinar), frontal eye fields, and the superior colliculus. The changes in shifts of covert attention must therefore be due to changes in cortical areas involved in the posterior attention network, particularly cortical areas such as the parietal cortex and the frontal eye fields (Hood, 1993, 1995; Johnson et al., 1991, 1998; Johnson & Tucker, 1996).

I have begun to study the development of cortical involvement in covert orienting using direct measures of brain activity (Richards, 2000d, 2001a,b,c). In one of these studies, infants were tested in the spatial cueing procedure (see Fig. 4.4). The goal of this study was to examine the "P1 validity effect" in young infants. The "P1" is an ERP component that consists of a large positive deflection in EEG about 100 ms alter stimulus presentation. The "N1" is a large negative deflection in EEG closely following the P1 component. Studies with adult participants have shown that the P1 and N1 ERP components are enhanced on the valid trials (cue validly predicts target) relative to invalid trials or neutral trials (see studies in Hillyard et al., 1995). These early ERP components reflect sensory and perceptual processes. The P1 validity effect suggests that covert attention to the cue enhances the early stages of information processing. The studies with infants (Richards, 2000d) found that the spatial relation between the cue and target significantly affected the ERP to the target onset. There was a larger ERP component amplitude occurring at about 135 ms when the cue and target were in the ipsilateral hemifields ("valid trials") than when the cue and target were in the contralateral fields ("invalid trials"). Figure 4.5 (top panels) shows the ERP response of



Figure 4.5. Top: ERP responses on the contralateral occipital electrode to the peripheral stimulus onset when it was presented as a target. The responses are presented separately for the three testing ages, and separately for the valid (solid line), invalid (small dashes), and no-cue control (long dashes) trials. The data are presented as the difference from the ERP on the no-stimulus control trial. The approximate locations of the P1 and N1 components are identified on each figure. Bottom: Topographical scalp potential maps for the P1 effect for the three testing ages. These maps plot the difference between the valid and no-cue control trials for the peak potential occurring between 50 and 200 ms after peripheral stimulus onset, which on the average occurred about 135 ms after peripheral stimulus onset (from Richards, 2000d, Localizing the development of covert attention in infants using scalp event-related potentials. *Developmental Psychology*, 36, 91–108. Copyright © 2000 by the American Psychological Association. Reprinted with permission.)

the contralateral occipital electrode for the ipsilateral, contralateral, and no-cue control trials plotted separately for 14-, 20-, and 26-week-old infants (Richards, 2000d). The validity effect on this positive ERP component did not occur (or was very small) in the 14-week-old infants, occurred at larger levels in the 20-week-old infants, and was at its largest in the 26-week-old infants. The topographical maps shown in Fig. 4.5 (bottom panels) show that this effect was localized to the contralateral occipital area for the oldest infants, showed a wider spread over the cortex for the 20-week-olds, and was very small for the youngest infants. The results from this study indicate that infants were shifting attention to the cued location covertly and that this early sensory–perceptual gating occurs in infant attention as it does in adult attention.

The findings from this study shed some light on the development of covert attention and orienting in young infants. There was an interesting developmental dissociation in this study between the facilitation effect that occurred at all three ages, the inhibition of return effect that gradually increased over the three testing ages, and the increasing amplitude of the P1 validity effect over the three testing ages. It suggests that the infants at the youngest testing ages (i.e. 3 months) might show covert orienting to the exogenous peripheral target, but that this orienting occurs as a result of reflexive saccadic programming rather than a shift of attention (Hillyard et al., 1995; Hopfinger & Mangun, 1998). Alternatively, at 4.5 and 6 months of age the infants were shifting attention appropriately, resulting in facilitation, inhibition of return, and the P1 validity effect. The direct measurement of brain activity afforded by the ERP results supports the neurodevelopmental models that suggest that there is an increasing involvement in this age range of cortical attention areas that affect infant attentive behaviour.

SACCADE PLANNING

Primates have several types of eye movements that have been shown to be controlled by specific areas of the brain. Two of these in particular, reflexive saccades and voluntary saccades, have been examined in neurodevelopmental models and empirical studies of infant visual attention. The neural basis of these two types of eye movements has been outlined by Schiller (1985, 1998). "Reflexive saccades" are eye movements that occur in response to the sudden onset of peripheral stimuli. These eye movements are controlled by several subcortical neural areas (retina, lateral geniculate nucleus, superior colliculus) and perhaps by the primary visual area. "Voluntary saccades" are eye movements that are under voluntary control and are affected by attention. Consistent with their voluntary nature and the role of attention in these eye movements, there are several areas of the cortex that affect these eye movements. Of particular interest are the parietal cortex and frontal eye fields. Johnson's neurodevelopmental model (Johnson, 1990, 1995; Johnson et al., 1991, 1998) emphasizes the role of the primary visual cortex in delaying these attention-directed eye movements until the fourth or fifth post-natal month. Thus, it can be predicted that reflexive saccades occur predominantly (exclusively?) in the first few postnatal months followed by the onset of voluntary eye movements by about the fourth or fifth postnatal months.

Saccade planning has been studied in non-human primates and human adults. For example, when monkeys are trained to make a saccadic eye movement from a fixation point to a target in a location to which attention has been directed, activity in the frontal eye fields (and sensorimotor eye fields) precedes the eye movements (Boch & Goldberg, 1989; Bruce & Goldberg, 1984, 1985; Hanes & Schall, 1996; Hanes, Thompson, & Schall, 1995; Schall, 1991a,b, 1995; Schall & Hanes, 1993; Schall, Hanes, Thompson, & King, 1995). In human adults, cortical influence on saccade planning has been studied with EEG occurring in advance of the saccadic eye movement, "presaccadic ERP". This activity includes an early negativity occurring up to 1s prior to saccade onset, a positive component occurring 30-300ms prior to saccade onset, and a "spike potential" occurring just prior to saccade onset (Balaban & Weinstein, 1985; Becker, Hoehne, Iwase, & Kornhuber, 1973; Csibra, Johnson, & Tucker, 1997; Kurtzberg & Vaughan, 1980, 1982; Moster & Goldberg, 1990; Weinstein, Balaban, & Ver Hoeve, 1991). Several of these presaccadic ERP components differ when adults make voluntary eye movements to targeted locations from when adults make reflexive saccades to unexpected peripheral targets.

A number of recent studies have examined these presaccadic ERP changes in infants. An interesting series of studies is that of Csibra, Johnson, and Tucker (Csibra et al., 1997; Csibra, Tucker, & Johnson, 1998; Csibra, Tucker, Volein, & Johnson, 2000), who used a procedure in 6-month-old infants, 12-month-old infants, and adults in which a cue in an unexpected peripheral location was presented. The infants and adults showed the typical "gap effect" in which a fixationtarget temporal gap resulted in shorter saccadic reaction time than did a fixation-target pair that overlapped. The presaccadic ERP in these studies was recorded with 64 channels. Figure 4.6 (top panel) shows the presaccadic ERP at the Pz electrode for the participants at different ages. There was a clear spike potential for the adults, a smaller one for the 12-month-olds, and no spike potential for the voungest infants. The topographical potential maps for the 12-month-olds and adults are shown in Fig. 4.6 (bottom panels). A clear spike potential is distributed primarily contralateral to the eye movement over the parietal area. The presumed origin of the spike potential is the parietal cortex and these results suggest that saccade planning by this area is developing throughout the early part of childhood.

I have found in three studies some provocative results for 3- to 6-monthold infants making eye movements to an expected location (Richards, 2000d, 2001a,b). These studies involved the spatial cueing procedure (see Fig. 4.4) in which a cue predicted the upcoming target location, did not predict the location, or no cue occurred. I argued that in the case of the cue predicting the target location, the infant could "plan" to make a saccade to the location in which the cue occurred (Richards, 2001c). Alternatively, if a target occurred in an unexpected



Figure 4.6. The presaccadic ERP to an unexpected peripheral target in 6- and 12-month-old infants and adults. Top: The ERP at the Pz electrode immediately preceding the saccade to the target. Bottom: Topographical potential map for the spike potential in 12-month-old infants and in adults (from Csibra et al., 2000).

location (i.e. contralateral to the cue, or no cue occurred) then the infant must make a reflexive saccade. The ERP that occurred immediately before the infant made a saccade to the target was recorded. Figure 4.7 shows the ERP changes for 4 of 40 electrode sites and Fig. 4.8 shows topographical maps at about 50 and 300ms preceding saccade onset. On the trials in which the cue predicted the location of the target, there was a large positive presaccadic potential that occurred about 50ms before the saccade occurred (Fig. 4.7, top panels). This ERP component occurred primarily over the frontal areas (Fig. 4.8, left figure). For trials on which there was no target and the infant made an eye movement, or for which the target appeared in a location that was unexpected given the cued location, this presaccadic ERP component did not occur. Alternatively, on the trials on which the infant made a saccade to the location predicted by the target whether the target was there or not, there was a positive potential occurring over the parietal cortex (Fig. 4.8, right figure), compared with eye movements to targets occurring in unexpected locations (Fig. 4.7, bottom panels). These results suggest that the infant first plans to make a saccade to an expected peripheral location (parietal cortex), uses the expected target to guide the planned saccade (frontal cortex), and then makes the saccade.

The results from one of these studies (Richards, 2001a) and from recently collected data with 128 electrodes were used to identify the area of the cortex



Figure 4.7. The ERP responses for 4 of 40 electrode locations. The presaccadic ERP for F4 and FC6 show a large presaccadic positive ERP component that occurred about 50ms before saccade onset for cued-exogenous saccades (PSP50). The presaccadic ERP for P4 and PO6 show a large presaccadic positive ERP component that occurred about 300ms before saccade onset for the cued-exogenous and endogenous saccades (PSP300) (from Richards, 2001b, Cortical indices of saccade planning following covert orienting in 20-week-old infants. *Infancy*, 2, 135–157. Reprinted with permission of Lawrence Erlbaum Associates.)



Figure 4.8. Topographical scalp potential maps for the PSP50 and PSP300 components for the difference between the cued-exogenous and the combined endogenous and cued-exogenous saccades (left) and for the difference between the combined cued-exogenous and endogenous, and the cued-exogenous saccades (right). The maps were plotted as if the infant were making a saccade towards the left side (from Richards, 2001b, Cortical indices of saccade planning following covert orienting in 20-week-old infants. *Infancy*, 2, 135–157. Reprinted with permission of Lawrence Erlbaum Associates.)

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involved in this presaccadic activity (Richards, 2001b). "Equivalent current dipole analysis" ("brain electrical source analysis"; Huizenga & Molenaar, 1994; Nunez, 1990; Scherg, 1990, 1992; Scherg & Picton, 1991; see also Chapter 2) hypothesizes specific locations for a neural generator of the recorded ERP activity and compares the activity generated on the scalp by the hypothesized dipole with the recorded cortical potentials. Plate 3 (top left figure) shows the topographical scalp potential map for presaccadic ERP potential occurring about 50 ms before the saccade to the expected location (i.e. Fig. 4.7 top panels; Fig. 4.8, left panel). A current dipole located in the area of the frontal eve fields (Plate 3 bottom figures) was used to generate a topographical map of this effect (Plate 3 top right figure). The hypothesized cortical dipole generated a scalp potential map that closely mapped the recorded ERP. This analysis is consistent with the interpretation that the eve movements to the target in the planned location involve cortical areas that control planned eve movements. These results also show that the brain areas controlling planned saccades can be measured directly with scalp-recorded ERPs.

CONCLUSIONS

- 1. Developmental changes in attention are caused by changes in the brain.
- 2. Infant recognition memory development parallels brain-attention development.
- Neurodevelopment bases of covert orienting and eye movement planning can be examined directly in young infants.
- New techniques in recording and quantification of EEG and ERP will result in more studies using direct methods of brain measurement in the study of attention development.

Attention shows development over the human lifespan, and much of that development is due to concomitant changes in the brain areas controlling attention. This chapter has emphasized neurodevelopmental models of visual attention in the first 6 to 12 months of infancy. This was chosen because of explicit neurodevelopment models that relate changes in the brain areas involved in vision to developmental changes in infant visual behaviour and visual attention. Such neurodevelopmental approaches to infant behaviour could be discussed that related brain changes to other sensory systems or to higher cognitive functions (Colombo, 1995; Ruff & Rothbart, 1996). Developmental changes in attention that occur in children, adolescents, and adults could probably use such models, although these models are rare at this time. The chapter emphasized the use of direct measures of brain activity, such as scalp-recorded ERP changes that occur in tasks requiring visual attention.

A major shift now occurring in this area of research is the use of high-density EEG and ERP for the identification of specific cortical areas involved in attention. The high-density ERP recording increases the resolution of ERP even if used without topographical methods or cortical source analysis. Such enhanced resolution, along with quantitative techniques, will allow the identification of specific scalp sites or spatiotemporal localizing of such effects. Perhaps the brightest light on this horizon is the ability to pinpoint specific areas of the cortex that generate the scalp-recorded EEG/ERP with equivalent current dipole analysis or associated cortical source techniques. The study reported in this chapter identifying the frontal eye fields as the likely source for the presaccadic ERP effects in infant planned saccades is such an example. This is particularly critical for infants and very young children for whom other neuroimaging techniques are still not feasible (see Chapter 2). Such techniques should lead to a better understanding of the relation between brain development and the development of visual attention in infants and children.

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REFERENCES

- Atkinson, J., & Braddick, O. (2001). Visual development. In M. de Haan & M.H. Johnson (Eds.), The cognitive neuroscience of development. Hove, UK: Psychology Press.
- Balaban, C.D., & Weinstein, J.M. (1985). The human pre-saccadic spike potential: Influences of a visual target, saccade direction, electrode laterality and instructions to perform saccades. *Brain Research*, 347, 49–57.
- Becker, W., Hoehne, O., Iwase, K., & Kornhuber, H.H. (1973). Cerebral and ocular muscle potentials preceding voluntary eye movements in man. *Electroencephalography* and Clinical Neurophysiology Supplement, 33, 99–104.
- Bell, M.A. (1998). In J.E. Richards (Ed.), Cognitive neuroscience of attention: A developmental perspective (pp. 287–316). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.
- Berg, W.K., & Richards, J.E. (1997). Attention across time in infant development. In P.J. Lang, R.F. Simons, & M.T. Balaban (Eds.), Attention and orienting: Sensory and motivational processes (pp. 347–368). Mahwah, NJ: Lawrence Erlbaum Associates Inc.
- Boch, R.A., & Goldberg, M.E. (1989). Participation of prefrontal neurons in the preparation of visually guided eye movements in the rhesus monkey. *Journal of Neurophysiology*, 61, 1064–1084.
- Bronson, G.W. (1974). The postnatal growth of visual capacity. Child Development, 45, 873–890.
- Bronson, G.W. (1997). The growth of visual capacity: Evidence from infant scanning patterns. In C. Rovee-Collier & L.P. Lipsitt (Eds.), Advances in infancy research (Vol. 11, pp. 109–141). Greenwich, CT: Ablex.
- Bruce, C.J., & Goldberg, M.E. (1984). Physiology of the frontal eye fields. Special issue: The frontal lobes—uncharted provinces of the brain. *Trends in Neurosciences*, 7, 436–441.
- Bruce, C.J., & Goldberg, M.E. (1985). Primate frontal eye fields: I. Single neurons discharging before saccades. *Journal of Neurophysiology*, 53, 603–635.

- Butcher, P.R., Kalverboer, A.F., & Gueze, R.H. (1999). Inhibition of return in very young infants: A longitudinal study. *Infant Behaviour and Development*, 22, 303–319.
- Canfield, R.L., Smith, E.G., Brezsnyak, M.E., & Snow, K.L. (1997). Information processing through the first year of life. *Monographs of the Society for Research in Child Development*, Serial No 250.
- Casey, B.J., & Thomas, K.M. (2002). Methods in cognitive neuroscience. In M. de Haan & M.H. Johnson (Eds.), *The cognitive neuroscience of development*. Hove, UK: Psychology Press.
- Clohessy, A.B., Posner, M.I., Rothbart, M.K., & Vecera, S.P. (1991). The development of inhibition of return in early infancy. *Journal of Cognitive Neuroscience*, 3, 345–350.
- Colombo, J. (1995). On the neural mechanism underlying developmental and individual differences in visual fixation in infancy: Two hypotheses. *Developmental Review*, 15, 97–135.
- Courchesne, E. (1977). Event-related brain potentials: Comparison between children and adults. Science, 197, 589–592.
- Courchesne, E. (1978). Neurophysiological correlates of cognitive development: Changes in long-latency event-related potentials from childhood to adulthood. *Electroencephalography and Clinical Neurophysiology*, 45, 468–482.
- Courchesne, E., Ganz, L., & Norcia, A.M. (1981). Event-related brain potentials to human faces in infants. *Child Development*, 52, 804–811.
- Csibra, G., Johnson, M.H., & Tucker, L.A. (1997). Attention and oculomotor control: A high-density ERP study of the gap effect. *Neuropsychologica*, 35, 855–865.
- Csibra, G., Tucker, L.A., & Johnson, M.H. (1998). Neural correlates of saccade planning in infants: A high-density ERP study. *International Journal of Psychophysiology*, 29, 201–215.
- Csibra, G., Tucker, L.A., Volein, A., & Johnson, M.H. (2000). Cortical development and saccade planning: The ontogeny of the spike potential. *NeuroReport*, 11, 1069–1073.
- de Haan, M., & Nelson, C.A. (1997). Recognition of the mother's face by six-month-old infants: A neurobehavioural study. *Child Development*, 68, 187–210.
- Fagan, J.F. (1974). Infant recognition memory: The effects of length of familiarization and type of discrimination task. *Child Development*, 59, 1198–1210.
- Frick, J., & Richards, J.E. (2001). Individual differences in infants' recognition of briefly presented visual stimuli. *Infancy*, 2, 331–352.
- Hanes, D.P., & Schall, J.D. (1996). Neural control of voluntary movement initiation. Science, 274, 427–430.
- Hanes, D.P., Thompson, K., & Schall, J.D. (1995). Relationship of presaccadic activity in frontal eye field and supplementary eye field to saccade initiation in macaque: Poisson spike train analysis. *Experimental Brain Research*, 103, 85–96.
- Heilman, K.M., Watson, R.T., Valenstein, E., & Goldberg, M.E. (1987). Attention: Behaviour and neural mechanisms. In V.B. Mountcastle, F. Plum, & S.R. Geiger (Eds.), *Handbook of physiology* (pp. 461–481). Bethesda, MD: American Physiological Society.
- Hillyard, S.A., Mangun, G.R., Woldroff, M.G., & Luck, S.J. (1995). Neural systems mediating selective attention. In M.S. Gazzaniga (Ed.), *Cognitive neurosciences* (pp. 665–682). Cambridge, MA: MIT Press.
- Hood, B.M. (1993). Inhibition of return produced by covert shifts of visual attention in 6-month-old infants. *Infant Behaviour and Development*, 16, 245–254.
- Hood, B.M. (1995). Shifts of visual attention in the human infant: A neuroscientific approach. Advances in Infancy Research, 10, 163–216.

- Hood, B.M., & Atkinson, J. (1991). Shifting covert attention in infants. Paper presented at the meeting of the Society for Research in Child Development, Seattle, WA, April 1991.
- Hood, B.M., Atkinson, J., & Braddick, O.J. (1998). Selection-for-action and the development of orienting and visual attention. In J.E. Richards (Ed.), *Cognitive neuroscience* of attention: A developmental perspective (pp. 219–250). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.
- Hopfinger, J., & Mangun, G.R. (1998). Reflexive attention modulates processing of visual stimuli in human extrastriate cortex. *Psychological Science*, 9, 441–447.
- Huizenga, H.M., & Molenaar, P.C.M. (1994). Estimating and testing the sources of evoked potentials in the brain. *Multivariate Behavioural Research*, 29, 237–262.
- Johnson, M.H. (1990). Cortical maturation and the development of visual attention in early infancy. Journal of Cognitive Neuroscience, 2, 81–95.
- Johnson, M.H. (1995). The development of visual attention: A cognitive neuroscience perspective. In M.S. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 735–747). Cambridge, MA: MIT Press.
- Johnson, M.H. (1997). Developmental cognitive neuroscience. London: Blackwell.
- Johnson, M.H., Gilmore, R.O., & Csibra, G. (1998). Toward a computational model of the development of saccade planning. In J.E. Richards (Ed.), *Cognitive neuroscience of attention: A developmental perspective* (pp. 103–130). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.
- Johnson, M.H., Posner, M.I., & Rothbart, M.K. (1991). Components of visual orienting in early infancy: Contingency learning, anticipatory looking and disengaging. *Journal of Cognitive Neuroscience*, 3, 335–344.
- Johnson, M.H., & Tucker, L.A. (1996). The development and temporal dynamics of spatial orienting in infants. *Journal of Experimental Child Psychology*, 63, 171–188.
- Karmel, B.Z. & Maisel, E.G. (1975). A neuronal activity model for infant visual attention. In L.B. Cohen & P. Salapatek (Eds.), *Infant perception: From sensation to cognition* (Vol. 1, pp. 77–131). New York: Academic Press.
- Kurtzberg, D., & Vaughan, H.G. (1980). Differential topography of human eye movement potentials preceding visually triggered and self-initiated saccades. In H.H. Kornhuber & L. Deecke (Eds.), *Motivation, motor and sensory processes of the brain* (pp. 203–208). Amsterdam: Elsevier Science Publishers.
- Kurtzberg, D., & Vaughan, H.G. (1982). Topographic analysis of human cortical potentials preceding self-initiated and visually triggered saccades. *Brain Research*, 243, 1–9.
- Maurer, D., & Lewis, T.L. (1979). A physiological explanation of infants' early visual development. *Canadian Journal of Psychology*, 33, 232–252.
- Maurer, D., & Lewis, T.L. (1991). The development of peripheral vision and its physiological underpinnings. In M.J.S. Weiss & P.R. Zelazo (Eds.), Newborn attention: Biological constraints and the influence of experience (pp. 218–255). Norwood, NJ: Ablex Publishing Co.
- Maurer, D., & Lewis, T.L. (1998). Overt orienting toward peripheral stimuli: Normal development and underlying mechanisms. In J.E. Richards (Ed.), Cognitive neuroscience of attention: A developmental perspective (pp. 51–102). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.
- Mesulam, M.M. (1983). The functional anatomy and hemispheric specialisation for directed attention. *Trends in Neuroscience*, 6, 384–387.
- Moster, M.L., & Goldberg, G. (1990). Topography of scalp potentials preceding selfinitiated saccades. *Neurology*, 40, 644–648.

- Nelson, C.A. (1994). Neural correlates of recognition memory in the first postnatal year. In G. Dawson & K.W. Fischer (Eds.), *Human behaviour and the developing brain* (pp. 269–313). New York: Guilford Press.
- Nelson, C.A., & Collins, P.F. (1991). Event-related potential and looking-time analysis of infants' responses to familiar and novel events: Implications for visual recognition memory. *Developmental Psychology*, 27, 50–58.
- Nelson, C.A., & Collins, P.F. (1992). Neural and behavioural correlates of visual recognition memory in 4- and 8-month-old infants. *Brain and Cognition*, 19, 105–121.
- Nelson, C.A., & deRegnier, R.A. (1992). Neural correlates of attention and memory in the first year of life. *Developmental Neuropsychology*, 8, 119–134.
- Nelson, C.A., & Dukette, D. (1998). In J.E. Richards (Ed.), Cognitive neuroscience of attention: A developmental perspective (pp. 327–362). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.
- Nelson, C.A., & Monk, C. (2001). The use of event-related potentials in the study of cognitive development. In C.A. Nelson & M. Luciana (Eds.), *Handbook of developmental* cognitive neuroscience (pp. 125–136). Cambridge, MA: MIT Press.
- Nunez, P.L. (1990). Localization of brain activity with electroencephalography. Advances in Neurology, 54, 39–65.
- Posner, M.I. (1980). Orienting of attention. Quarterly Journal of Experimental Psychology, 32, 3–25.
- Posner, M.I. (1995). Attention in cognitive neuroscience: An overview. In M.S. Gazzaniga (Ed.), Cognitive neurosciences (pp. 615–624). Cambridge, MA: MIT Press.
- Posner, M.I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D.G. Bouwhis (Eds.), Attention and performance X (pp. 531–556). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.
- Posner, M.I., & Petersen, S.E. (1990). The attention system of the human brain. Annual Review of Neuroscience, 13, 25–42.
- Rafal, R.D. (1998). The neurology of visual orienting: A pathological disintegration of development. In J.E. Richards (Ed.), *Cognitive neuroscience of attention: A developmental perspective* (pp. 181–218). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.
- Ray, W.J. (1990). Electrical activity of the brain. In J.T. Cacioppo & L.G. Tassinary (Eds.), Principles of psychophysiology: Physical, social, and inferential elements (pp. 385–412). Cambridge: Cambridge University Press.
- Richards, J.E. (1989). Development and stability in visual sustained attention in 14, 20, and 26 week old infants. *Psychophysiology*, 26, 422–430.
- Richards, J.E. (1995). Infant cognitive psychophysiology: Normal development and implications for abnormal developmental outcomes. In T.H. Ollendick & R.J. Prinz (Eds.), Advances in Clinical Child Psychology (Vol 17, pp. 77–107). New York: Plenum Press.
- Richards, J.E. (1997). Effects of attention on infants' preference for briefly exposed visual stimuli in the paired-comparison recognition-memory paradigm. *Developmental Psychology*, 33, 22–31.
- Richards, J.E. (1998). Development of selective attention in young infants. Developmental Science, 1, 45–51.
- Richards, J.E. (2000a). Attention in young infants: A developmental psychophysiological perspective. In C.A. Nelson & M. Luciana (Eds.), *Developmental cognitive neuroscience*. Cambridge, MA: MIT Press.
- Richards, J.E. (2000b). Development of multimodal attention in young infants: Modification of the startle reflex by attention. *Psychophysiology*, 37, 1–11.

- Richards, J.E. (2000c). The effect of attention on the recognition of brief visual stimuli: An ERP study. Paper presented at the International Conference on Infancy Studies, Brighton, UK, July, 2000.
- Richards, J.E. (2000d). Localizing the development of covert attention in infants using scalp event-related-potentials. *Developmental Psychology*, 36, 91–108.
- Richards, J.E. (2000e). The development of covert attention to peripheral targets and its relation to attention to central visual stimuli. Paper presented at the International Conference for Infancy Studies, Brighton, UK, July 2000.
- Richards, J.E. (2001a). Cortical indices of saccade planning following covert orienting in 20-week-old infants. *Infancy*, 2, 135–157.
- Richards, J.E. (2001b). Using high-density EEG recording to localize cortical sources of infant attention. Paper presented at the Society for Research in Child Development, Minneapolis, MN, April 2001.
- Richards, J.E., & Casey, B.J. (1990). Infant visual recognition memory performance as a function of heart rate defined phases of attention. *Infant Behaviour and Development*, 13, 585.
- Richards, J.E., & Casey, B.J. (1991). Heart rate variability during attention phases in young infants. *Psychophysiology*, 28, 43–53.
- Richards, J.E., & Casey, B.J. (1992). Development of sustained visual attention in the human infant. In B.A. Campbell, H. Hayne, & R. Richardson (Eds.), Attention and information processing in infants and adults (pp. 30–60). Mahwah, NJ: Lawrence Erlbaum Associates Inc.
- Richards, J.E., & Holley, F.B. (1999). Infant attention and the development of smooth pursuit tracking. *Developmental Psychology*, 35, 856–867.
- Richards, J.E., & Hunter, S.K (1997). Peripheral stimulus localization by infants with eye and head movements during visual attention. *Vision Research*, 37, 3021–3035.
- Richards, J.E., & Hunter, S.K. (1998). Attention and eye movement in young infants: Neural control and development. In J.E. Richards (Ed.), *Cognitive neuroscience of attention: A developmental perspective* (pp. 131–162). Mahwah, NJ: Lawrence Erlbaum Associates Inc.
- Richards, J.E., & Lansink, J.M. (1998). Distractibility during visual fixation in young infants: The selectivity of attention. In C. Rovee-Collier, L. Lipsitt, & H. Hayne (Eds.), Advances in infancy research (Vol. 13, pp. 407–444). Norwood, NJ: Ablex Publishing Co.
- Robbins, T.W., & Everitt, B.J. (1995). Arousal systems and attention. In M.S. Gazzaniga (Ed.), Cognitive neurosciences (pp. 703–720). Cambridge, MA: MIT Press.
- Ruff, H.A., & Rothbart, M.K. (1996). Attention in early development. New York: Oxford University Press.
- Salapatek, P. (1975). Pattern perception in early infancy. In L. Cohen & P. Salapatek (Eds.), *Infant perception*. New York: Academic Press.
- Schall, J.D. (1991a). Neuronal activity related to visually guided saccadic eye movements in the supplementary motor area of rhesus monkeys. *Journal of Neurophysiology*, 66, 530–558.
- Schall, J.D. (1991b). Neuronal activity related to visually guided saccades in the frontal eye fields of rhesus monkeys: Comparison with supplementary eye fields. *Journal of Neurophysiology*, 66, 559–579.
- Schall, J.D. (1995). Neural basis of saccade target selection. *Reviews in the Neurosciences*, 6, 63–85.
- Schall, J.D., & Hanes, D.P. (1993). Neural basis of saccade target selection in frontal eye field during visual search. *Nature*, 366, 467–469.

Schall, J.D., Hanes, D.P., Thompson, K.G., & King, D.J. (1995). Saccade target selection in frontal eye field of macaque: I. Visual and premovement activations. *Journal of Neuroscience*, 15, 6905–6918.

Scherg, M. (1990). Fundamentals of dipole source potential analysis. In F. Grandori, M. Hoke, & G.L. Romani (Eds.), Auditory evoked magnetic fields and potentials (pp. 40–69). Basel: Karger.

Scherg, M. (1992). Functional imaging and localization of electro-magnetic brain activity. Brain Topography, 5, 103–111.

- Scherg, M., & Picton, T.W. (1991). Separation and identification of event-related potential components by brain electrical source analysis. In C.H.M. Brunia, G. Mulder, & M.N. Verbaten (Eds.), *Event-related brain research* (pp. 24–37). Amsterdam: Elsevier.
- Schiller, P.H. (1985). A model for the generation of visually guided saccadic eye movements. In D. Rose & V.G. Dobson (Eds.), *Models of the visual cortex* (pp. 62–70). New York: John Wiley.

Schiller, P.H. (1998). The neural control of visually guided eye movements. In J.E. Richards (Ed.), Cognitive neuroscience of attention: A developmental perspective (pp. 3–50). Mahwah, NJ: Lawrence Erlbaum Associates Inc.

Schneider, G. (1969). Two visual systems. Science, 163, 895-902.

- Simion, F., Valenza, E., Umilta, C., & Barba, B.D. (1995). Inhibition of return in newborns is temporo-nasal asymmetrical. *Infant Behaviour and Development*, 18, 189–194.
- Smith, E.G., & Canfield, R.L. (1998). Two-month-olds make predictive saccades: Evidence for early frontal lobe function. Paper presented at the International Society for Infant Studies conference, Atlanta, GA.
- Swick, D., Kutas, M., & Neville, H.J. (1994). Localizing the neural generators of eventrelated brain potentials. In A. Kertesz (Ed.), *Localization and neuroimaging in neuropsychology. Foundations of neuropsychology* (pp. 73–121). San Diego: Academic Press.

Tucker, D.M. (1993). Spatial sampling of head electrical fields: The geodesic sensor net. Electroencephalography and Clinical Neurophysiology, 87, 154–163.

Tucker, D.M., Liotti, M., Potts, G.F., Russell, G.S., & Posner, M.I. (1994). Spatiotemporal analysis of brain electrical fields. *Human Brain Mapping*, 1, 134–152.

Valenza, E., Simion, F., & Umilta, C. (1994). Inhibition of return in newborn infants. Infant Behaviour and Development, 17, 293–302.

Weinstein, J.M., Balaban, C.D., & VerHoeve, J.N. (1991). Directional tuning of the human presaccadic spike potential. *Brain Research*, 543, 243–250.

Wentworth, N., & Haith, M.M. (1998). Infants' acquisition of spatiotemporal expectations. Developmental Psychology, 34, 247–257.

Wentworth, N., Haith, M.M., & Karrer, R. (2001). Behavioural and cortical measures of infants' visual expectations. *Infancy*, 2, 175–196.

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CHAPTER FIVE

A cognitive neuroscience perspective on early memory development

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INTRODUCTION

It is difficult to date a historical interest in memory development. Clearly Freud was enamoured by the topic, as it lay at the route of his speculation that early life experiences have a profound and central role in many aspects of one's day-to-day adult life (Freud, 1965). Indeed, many attribute to Freud the notion that we fail to remember the events that transpire during our first few years of life (the concept of infantile amnesia) because we repress these early memories. Although such speculation was then, and remains, without empirical support, this view of early memory continues to dominate some schools of psychoanalytic thought and psychotherapeutic practice (e.g. it is behind the movement to help patients "recover" early childhood memories). Further, it has weaved its way into some contemporary views of attachment theory (e.g. the concept of inner working models, whereby infants develop a mental representation of their attachment relationship with their primary caretaker; see Bowlby, 1969).

Although clinically relevant, approaching how memory develops by studying how (and why) early memories are forgotten might not be the most fruitful avenue to pursue with regard to how early memories are formed and stored. For this reason, several investigators have formulated more developmentally oriented and/or sensitive approaches to the concept of infantile amnesia and early memory development. For example, Howe and Courage (1993, 1997) argue that the failure to recall the events from our infancy is not due to encoding or retrieval errors, or indeed any fundamental immaturity in the memory system *per se*; rather, they argue that the infant lacks what they refer to as the "cognitive self". With the