

# Visual Attention and the Control of Eye Movements in Early Infancy

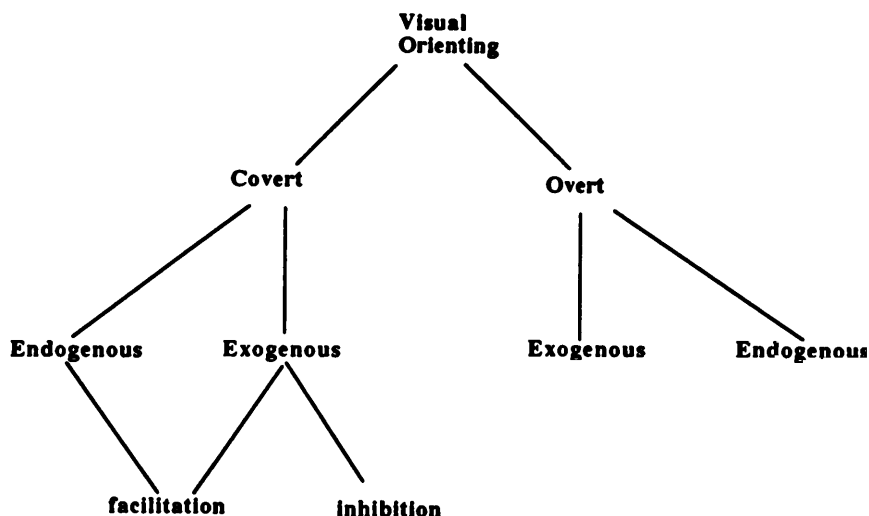
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**ABSTRACT** Experiments concerned with the development of volitional (endogenous) control of eye movements (overt orienting) in infants are described. This evidence indicates that infants are capable of the voluntary control of eye movements by around 4 months of age. Next, experiments that attempt to measure covert shifts of visual attention in early infancy are reviewed, and the results of a study involving the exogenous cueing of covert attention reported. These results indicate that 4-month-old infants, like adults, show both facilitation and subsequent inhibition of responding to a cued spatial location. In contrast, a group of 2-month-old infants did not show these effects within the temporal parameters studied. Finally, I speculate on the underlying neural basis of these developments, and on their implication for the relation between covert shifts of attention and eye movements.

## 11.1 INTRODUCTION

It has become evident in recent years that there are multiple brain pathways involved in the control of eye movements and visual attention in adults (Schiller 1985; Posner and Peterson 1990). Investigating the sequential development of these pathways, and the construction of the visual attention system during ontogeny, may be informative given the obvious difficulty in analyzing the complex combinations of hierarchical and parallel systems found in adults (see Johnson 1990, 1994). In this chapter I review studies and present new evidence on the ontogeny of both overt and covert aspects of visual orienting, focusing in particular on the transition from exogenous to endogenous control. I conclude by assessing the implications of these experiments on development for the debate in adult literature about the role of covert shifts of attention in saccade execution and planning.

While our understanding of visual attention and orienting in adults is far from complete, a number of distinctions have been proposed that will be helpful in our analysis of the ontogeny of attention (see fig. 11.1). Eye movements that shift gaze from one location to another may be referred to as overt orienting. In contrast, shifts of visual attention between spatial locations or objects that occur independently of eye and head movements are referred to as covert (Posner 1980). Only in the past few years has work on covert shifts of attention in infancy been performed, and much of that work is reviewed in this chapter. Although shifts of covert visual attention are, by definition, dissociable from eye and head movements, they may be clearly related to



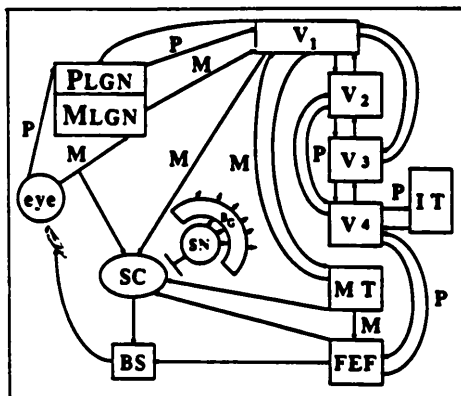
**Figure 11.1** An illustration of some dissociations used in the literature on visual attention.

overt orienting in some respects. The exact relation between covert attention and overt orienting will be discussed in more detail later.

A further distinction in the adult literature is that between *endogenous* and *exogenous* control. This distinction refers to whether, for example, responses to a particular spatial location were cued by a briefly presented stimulus that appeared at that location (exogenous), or whether that spatial location was cued by a more indirect form of instruction to the subject, such as a centrally presented arrow pointing to the right or left, or a verbal instruction to look in a certain direction (endogenous). This distinction is of interest in development since the onset of endogenous control over eye movements may be indicative of the transition from a primarily input-driven, automatic form of orienting to a system under the influence of volitional (and possibly conscious) control.

## 11.2 OVERT VISUAL ORIENTING IN EARLY INFANCY

Bronson (1974, 1982) reviewed evidence in support of the contention that the newborn human infant sees primarily through the subcortical retinotectal visual pathway and that it is only by around 2 or 3 months of age that the primary visual pathway becomes functional to the extent that it influences the visually guided behavior of the young infant. This putative shift of visually guided behavior from subcortical to cortical processing, he argued, was accompanied by a shift from exogenous (input-driven) orienting to endogenous (volitional) orienting. Atkinson (1984) and Johnson (1990) have updated and extended Bronson's original account in the light of more recent knowledge about the independent streams of visual processing in the cortex (de Yoe and Van Essen 1988; Van Essen 1985). Both Atkinson and Johnson proposed models based on the sequential development of particular cortical streams, resulting in phases of partial cortical functioning.



**Figure 11.2** A schematic representation of the model proposed by Schiller (1985) for the neuroanatomical pathways thought to underlie oculomotor control in primates. LGN = lateral geniculate nucleus; SC = superior colliculus; SN = substantia nigra; BG = basal ganglia; BS = brainstem; FEF = frontal eye fields; M = Broad band (magnocellular) stream; P = color opponent (parvocellular) stream. (Adapted from Schiller 1985.)

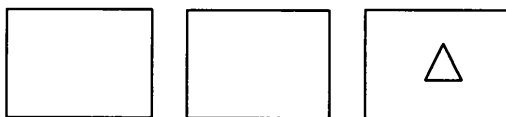
Figure 11.2 illustrates a number of pathways thought to underlie oculomotor control in the primate brain (Schiller 1985). In brief, these pathways are (1) a subcortical pathway involving the superior colliculus and thought to be involved in rapid, input-driven (exogenous) saccades; (2) a diffuse cortical projection to the superior colliculus via the basal ganglia and substantia nigra, apparently involved in the regulation of the colliculus; (3) a cortical pathway that passes through area MT and that is probably involved in motion detection and the smooth tracking of moving stimuli; and (4) a cortical pathway through the frontal eye fields that is important for more complex forms of scanning patterns.

Johnson (1990) used evidence from human postnatal developmental neuroanatomy to argue for the following developmental sequence of onset: (1) before (2), then (3), then (4). This developmental sequence was then traced to the onset of components of visual orienting. For example, the development of the frontal eye field pathway (4) at around 3 to 4 months of age coincides with the onset of "anticipatory" saccades, the predictive tracking of moving stimuli, and the ability to use prior information to guide subsequent saccades. The onset of this endogenous eye movement control raises the issue of its interaction with exogenously driven saccades, such as those that are the product of the subcortical pathway (1). In adult subjects, the interaction between endogenous and exogenous eye movement systems can be studied in so-called antisaccade tasks. In an antisaccade task subjects are instructed not to make a saccade toward a cue stimulus but rather to saccade in the opposite direction where a target stimulus is subsequently presented (Hallett 1978). One component of this task is that subjects have to inhibit a spontaneous, automatic (exogenous) eye movement toward a stimulus and direct their saccade in the opposite direction. Thus, it is of interest to apply this task to infants.

### Fixation Stimulus



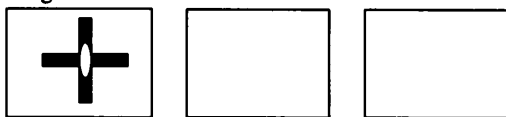
Cue 500 ms



Delay 400 ms



Target



**Figure 11.3** The order of presentation of stimuli in experiment 1.

### Experiment 1

Clearly, one cannot give verbal instructions to a young infant to look to the side opposite from where the first stimulus appears. Instead, we have to motivate the infant to want to look at a second (target) stimulus more than at the first (cue) stimulus. This can be done by making the second stimulus more dynamic and colorful than the first. Thus, over a series of trials an infant may learn to withhold a saccade to the first stimulus in order to anticipate the appearance of the second (more attractive) stimulus. The first stimulus also becomes a cue to predict the appearance of the second stimulus on the opposite side (see fig. 11.3 for details of the stimulus presentation sequence).

In a pilot experiment to determine the feasibility of this approach, I have collected data from five 4-month-old infants (range, 122 to 128 days), with no known birth or other complications.<sup>1</sup> Using general procedures and stimuli described in detail for experiment 2, and a presentation schedule as shown in figure 11.3, a steady decrease in the extent of orienting toward the first (cue) stimulus was observed over a number of training trials from an initial level of over 80 percent to a level of under 50 percent (see table 11.1). Clearly this preliminary finding needs to be replicated and extended with a larger sample. Furthermore, control conditions in which the first stimulus (cue) is not predictive of the second (target) need to be run, in order to be sure that the infants are not merely habituating faster to the cue stimulus than to the target during the course of the experiment. While bearing these caveats in mind, the large number of trials in which infants made a saccade straight from the fixation

**Table 11.1** Frequency of Making a Saccade toward the First Stimulus within Each Block of Training Trials (mean and standard error)

Trial Numbers	1–4	5–8	9–12	13–16
Mean %	86.8	68.4	75.0	46.6
Standard error	8.1	9.3	12.4	14.1

point to the second (target) stimulus in the later stages of the experiment is consistent with the ability to inhibit input-driven saccades and may indicate volitional control over saccades. Further, the evidence that adults with lesions around the frontal eye fields cannot readily withhold input-driven saccades in a similar task (Guitton, Buchtel, and Douglas 1985) supports the contention that the development of this cortical structure is a necessary prerequisite for endogenous eye movement control in infants.

### 11.3 COVERT VISUAL ORIENTING IN EARLY INFANCY

At present we can study covert shifts of attention only in indirect ways. For example, in adults, covert attention may be directed to a spatial location by a very briefly presented visual stimulus. Although subjects do not make a saccade to this stimulus, they are faster to report (often by means of a button press) the appearance of a target stimulus in the cued location than in another location. With infants we are also limited to indirect methods of studying covert shifts of attention. Further, we have the problem that infants do not accept verbal instruction and are poor at motor responses readily used with adults such as a button press. One motor response that can be readily elicited even from very young infants is eye movement (overt orienting). Thus, in the experiments that follow, we attempt to use measures of overt orienting to study covert shifts of attention. We can do this by examining the influence of a cue stimulus, to which infants do not make an eye movement, on their subsequent saccades toward target stimuli. This approach has also been taken in some adult studies purporting to measure shifts of covert attention (e.g., Maylor 1985). Experiments in which infants do make a saccade toward a cue stimulus I will regard as not being informative with regard to covert shifts of visual attention.<sup>2</sup>

#### Exogenously Cued Covert Orienting

One way in which evidence for covert shifts of attention has been provided in adults is by studying the effect on detection of cueing saccades to a particular spatial location. A briefly presented cue serves to draw covert attention to the location, resulting in the subsequent facilitation of responses toward that location (Posner and Cohen 1980; Maylor 1985). This facilitatory effect lasts for about 100–200 ms in the adult. While facilitation of detection and saccades toward a covertly attended location occurs if the target stimulus appears very shortly after the cue offset, with longer latencies between cue and target,

inhibition of saccades toward that location occurs. This latter phenomenon, referred to as "inhibition of return" (Posner et al. 1985), may reflect an evolutionarily important mechanism for preventing attention returning to a spatial location that has been very recently processed. In adults facilitation is reliably observed when targets appeared at the cued location within about 100 ms of the cue, whereas targets that appear between 300 and 1,300 ms after a peripheral (exogenous) cue result in longer latency responses (e.g., Posner and Cohen 1980, 1984; Maylor 1985). It is worth noting that inhibition of return has been reported only in studies that involve exogenous, rather than endogenous, cueing.

One of the first studies pertinent to exogenous orienting in human infants was concerned with inhibition of return following overt orienting. Clohessy et al. (1991) report an experiment in which infants sat in front of three monitor screens on which colorful dynamic stimuli were presented. At the start of each trial an attractive fixation stimulus appeared on the central screen. Once the infant had fixated on this stimulus, a cue stimulus was presented on one of the two side monitor screens. When the infant had made a saccade toward the cue, it was turned off. Following this, infants returned their gaze to the center screen before an identical stimulus was presented bilaterally on both side screens. While infants of 3 months of age showed no significant preferential orienting toward the bilateral targets as a result of the cue, infants of 6 months of age oriented more toward the side opposite from that where the cue stimulus had appeared. The authors argued that this preferential orienting toward the opposite side from the cue is indicative of inhibition of return and its development between 3 and 6 months of age.

This result was replicated and extended by Hood and Atkinson (1991) also with 3- and 6-month-old infants. This study had two important differences from that reported by Clohessy et al. (1991). First, by using a shorter cue stimulus duration, Hood and Atkinson ensured that the infants did not make a saccade toward this stimulus. Thus, any effects of the cue presentation on subsequent saccades to the target could be attributed to a covert shift of attention during the cue presentation. The second difference was that Hood and Atkinson used unilateral target presentations, as opposed to the bilateral targets used by Clohessy and colleagues.

In their experiment Hood and Atkinson (1991) used a 100 ms cue that was followed by a target presented either ipsilateral or contralateral to the location where the cue had appeared. The target appeared either immediately after the cue or with an interstimulus interval (ISI) of 500 ms. The authors predicted that if the target appeared immediately after the cue, then they should see facilitation of reaction times to make a saccade toward the target when it appears on the ipsilateral side. In contrast, in trials where there was a 500 ms ISI between the stimuli they ought to see inhibition (slowed reaction times, RTs) for making a saccade toward the same location as that in which the cue had appeared.

The group of 6-month-old infants showed the predicted effects: a faster mean RT to make a saccade when the target appeared in the cued location on

the no ISI trials and a slower mean RT to make a saccade toward the cued location on the long ISI trials. However, the facilitation toward the cued location in the no ISI trials was a small (and nonsignificant) effect. Three-month-olds showed no significant effects of the cue in both the ISI and no ISI conditions, providing preliminary evidence that the mechanisms underlying the facilitation and inhibition following exogenous cueing develop between 3 and 6 months of age.

Hood (1993) reports an experiment similar to that of Hood and Atkinson (1991), but with an improved method allowing, among other things, more accurate assessment of RTs to make a saccade toward the target. In this experiment a group of 6-month-olds was exposed to a longer duration cue (180 ms) before immediately being presented with a single target on either the ipsilateral or the contralateral side. Infants did not make a saccade toward the cue since the attractive fixation stimulus was still being presented. This procedure resulted in a clear difference in mean RT to orient toward the target depending on whether it appeared in the same spatial location as the cue.<sup>3</sup>

The observations to date indicate that inhibition of return has developed by at least 6 months of age.<sup>4</sup> The issue of whether facilitatory effects are present by the same age remains unresolved, however, especially since inhibitory and facilitatory aspects of covert attention may have different neural substrates. Inhibition of return has been associated with midbrain oculomotor pathways (Posner et al. 1985; Rafal et al. 1989), while facilitatory effects have been attributed to cortical structures such as the parietal lobe (Posner et al. 1984).

The above review indicates that the state of our knowledge with regard to covert shifts of attention in infants is still somewhat patchy and provisional. For example, it is unclear whether facilitatory and inhibitory effects develop at the same age. Answering this question is of importance for understanding the extent to which they share a common neural substrate. Another factor is that while some studies have used RT as the dependent measure, others have used the direction of looking following bilateral target presentation. Further, the evidence for facilitatory effects is rather weak at present. Since all of the studies concerned with facilitatory effects so far have used unitary target presentations, an experiment involving bilateral target presentations might provide clearer evidence for this ability. In experiment 2, I report initial results from an exogenous cueing experiment on infants from 2 to 4 months of age.<sup>5</sup>

## **Experiment 2**

The procedure employed was a combination of those used in earlier studies. A single cue was presented for 100 ms on one of two side screens before bilateral targets were presented either 100 ms or 600 ms later. The 100 ms ISI should be short enough to produce facilitation, while the longer ISI should be long enough to produce inhibition. This procedure has the advantage that inhibition and facilitation can be studied in the same experiment, and two measures can be recorded: RT to make a saccade toward the target and direction of saccade.

**Subjects** Subjects were fifteen 2-month-olds (mean, 64.5 days; range, 57 to 71 days) and fifteen 4-month-old infants (mean, 127.3 days; range, 115 to 149 days), all with no known birth or other complications. The data from another three infants were discarded due to excessive fussing or drowsiness. Judging by the frequency of spontaneous smiles, infants appeared to enjoy the procedure.

**Procedure** The babies sat in a baby chair 55 cm from the center of three color monitors. Displays on these monitors were controlled by a Macintosh IICI microcomputer. Each trial began with the presentation of an attractor/fixation display on the central screen. The display was multicolored and dynamic, was accompanied by an auditory stimulus, and served to ensure that the infant was looking at the central screen at the start of each trial. The stimulus was composed of looming squares expanding and contracting to a regular bleeping sound and subtended 5 degrees of visual angle.

The experimenter could see the infant by means of a video camera mounted above the display screens. When the infant was judged to be looking at the attractor pattern, the experimenter pressed a key. The first thirty-two trials of the experiment consisted of short ISI and long ISI trials presented according to a pseudorandom schedule balanced within each block of four trials. Following this, if the infant was still in an attentive state, twenty-four baseline trials were run.

*Short ISI trials:* In these trials, when the experimenter was sure that the infant was looking toward the fixation stimulus he or she would press a key that initiated presentation of the cue stimulus on one of the two side screens (29 degrees to the right or left of the fixation stimulus). Whether the cue stimulus appeared to the right or to the left of the fixation stimulus was determined by a pseudorandom schedule. The cue stimulus was identical on both sides: a green diamond (3 degrees in width) that was presented for 100 ms. Following the offset of both the central stimulus and the cue, there was a 100-ms ISI before bilateral presentation of the target stimulus, both in the same location as that in which the cue had appeared and on the opposite side (fig. 11.4). The stimulus onset asynchrony<sup>6</sup> (SOA) was thus 200 ms. The target stimulus was composed of a dynamic, multicolored, rotating cogwheel shape. When the infant shifted gaze toward one or another of the targets, the trial was terminated and the next one begun by presentation of the central attractor stimulus.

*Long ISI trials:* These trials were identical to those previously described except that the ISI between the cue and the target was of a length likely to produce inhibition, 600 ms (an SOA of 700 ms).

*Baseline trials:* After infants had completed thirty-two trials as described above, most of the subjects were presented with twenty-four baseline trials in which no cue stimulus was presented. That is, after the offset of the fixation stimulus, bilateral targets appeared after an ISI of 600 ms.

Videotapes of infants' eye movements during the experiment were subsequently coded by persons, some of whom were not directly involved in the



### Fixation Stimulus



### 100 ms Cue



### 100 or 600 ms Gap



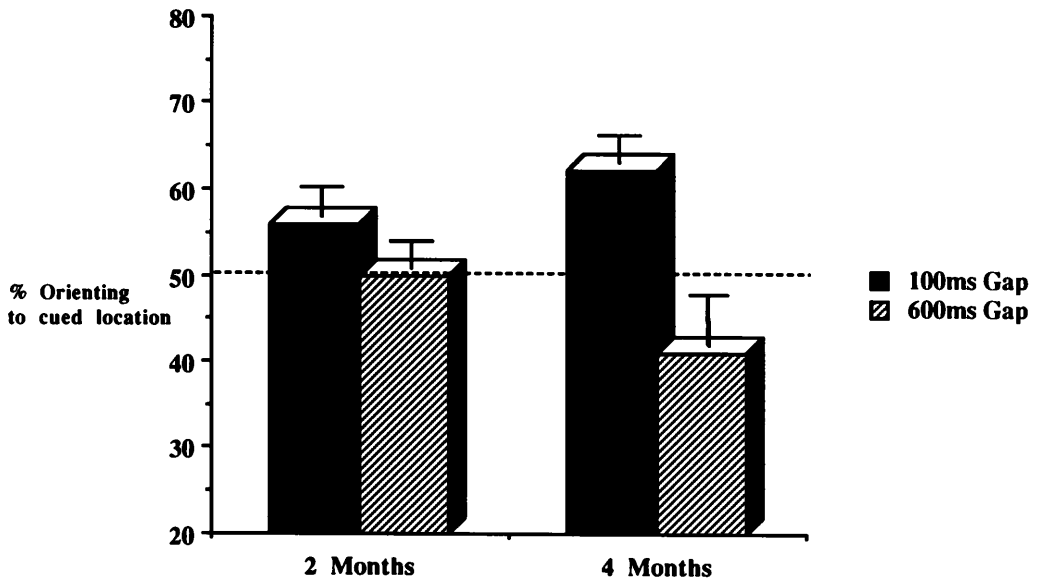
### Target



**Figure 11.4** The order of presentation of stimuli in experiment 2.

testing. Those trials in which the infant shifted gaze directly<sup>7</sup> from the fixation stimulus to one or another of the targets were analyzed with both the direction of the saccade (toward the cued or opposite side) and the RT to make a saccade being recorded. For most infants, at least twenty-four of the thirty-two experimental trials (75 percent) were scorable in this way. Trials were most commonly rejected because the infant was not looking at the fixation stimulus at the start of the trial, or because they looked up (to the camera) or down (to their feet) during the ISI. In the baseline trials, the median RT to make a saccade toward the target from the first six scorable trials was calculated. Reliability between coders was excellent (mean correlation of 0.92 between coders for RT and 1.0 for direction of looking).

**Results** Figure 11.5 illustrates the mean direction of orienting following presentation of the cue for the two age groups. A two-way ANOVA of mixed design (one between subjects factor—Age, and one within subjects factor—ISI length) was performed on the direction of orienting measures for the two age groups. There was a significant main effect of trial type (short or long ISI) on orienting ( $F(1,27) = 12.76, p = 0.0014$ ), and a borderline significant interaction between age group and trial type ( $F(1,27) = 4.00, p = 0.056$ ). This interaction indicated a different pattern of responding in the two age groups. Planned comparisons (paired *t*-tests) revealed no significant difference between the percentage of saccades toward the cued side between the short and long ISIs for the 2-month-old group ( $t = 1.23, df = 14, n.s.$ ) In contrast, the 4-month-old group showed a significantly greater tendency to orient to the

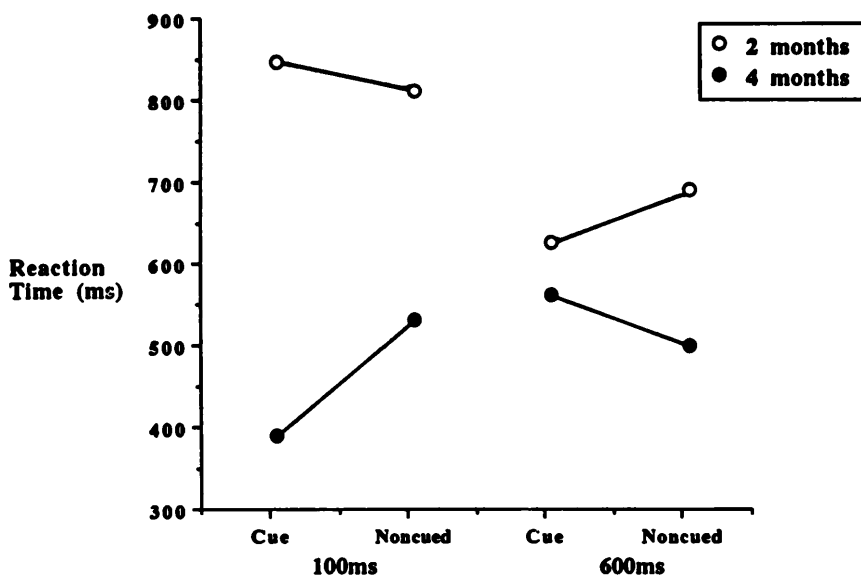


**Figure 11.5** The direction of orienting toward target bilateral target stimuli at short and long ISIs for the two age groups.

cued side in trials with the short ISI than they did in trials with the long ISI ( $t = 3.77, df = 13, p = 0.0023$ ). This effect was due to both increased orienting to the cued side in short ISI trials and decreased orienting to this side in the long ISI trials.

Figure 11.6 and table 11.2 show the RT data. A two-way ANOVA of mixed design was performed on the median reaction times to the four types of trials (cued and opposite sides at short and long ISIs, within subjects factor) for the two age groups (between subjects factor). There was a significant effect of Age (2 or 4 months) on RT ( $F(1,26) = 8.64, p = 0.0068$ ). Not surprisingly, 4-month-olds showed faster RTs. Although there was no significant overall effect of trial type ( $F(3,78) = 1.19, n.s.$ ), there was a highly significant interaction between age and trial type ( $F(3,78) = 5.30, p = 0.022$ ). This interaction indicated a different pattern of responding in the two age groups. Planned comparisons (paired  $t$ -tests) between cued and opposite trials for each SOA and age group revealed only one significant difference: that which exists between cued and opposite conditions with the short ISI in 4-month-olds ( $t = 2.90, df = 13, p = 0.0125$ ). The mean of median RT for the baseline trials are shown in table 11.2. The fact that the 2-month-olds readily oriented toward the target in the baseline condition is evidence that they had no difficulty in seeing the stimuli.

**Discussion** On the basis of the adult literature, we would expect that in short ISI trials subjects should respond more rapidly to stimuli appearing in the cued (valid) location (facilitation). If infants show this effect, then they should also orient more frequently to the cued side in the presence of bilateral targets.



**Figure 11.6** The mean reaction time to orient toward the cued and uncued sides at the two ISIs lengths and ages.

**Table 11.2** Mean of Median RT to Respond to the Target Stimulus for the Various Trial Types (in ms)

Age group	Baseline RT	100 Cued	100 Opposite	600 Cued	600 Opposite
2 months old	760	840	803	617	683
4 months old	447	400	523	553	490

In contrast, in the long ISI trials subjects may orient preferentially to the opposite (invalid) location (inhibition). From figure 11.5 it can be seen that there was no significant difference in the extent of orienting to the cued target between the long and the short ISI trials for the 2-month-old infants. The 4-month-olds, however, showed a significant difference in the extent to which they directed their orienting toward the cued target: at the short ISI they oriented more toward the cued target, while at the long ISI they oriented more toward the opposite target. Clearly, the difference between the 2- and 4-month-old groups is one of degree, suggesting that at least some 2-month-olds showed a tendency in the same direction as the older infants.

The RT data also show no significant effects in the 2-month-old infants (see fig. 11.6). At neither the short nor the long ISI trials was there a significant difference in their RT to orient toward the cued and opposite target. In contrast, 4-month-olds showed a clear facilitatory effect in the short ISI trials; their RT to orient toward the cued target was significantly shorter than their RT to orient toward the opposite target. Further, and consistent with inhibition of return, in the long ISI trials they were slower to make a saccade to the

cued location. The RT evidence is therefore consistent with both facilitation and inhibition to a cued location being present in the human infant by 4-months of age. There are, however, a number of reasons that we cannot yet conclude with any certainty that covert shifts of attention develop between 2 and 4 months of age.

The first of these reasons is that the pattern of "baseline" RT data obtained in this experiment is difficult to interpret. In order to provide strong evidence for facilitatory effects, baseline RT should ideally be significantly slower than cued trials at the short ISI. Similarly, for inhibition, the baseline RT should be significantly faster than the cued trial RT. In the 4-month-old group, the baseline RT was between the cued and uncued RTs for the short ISI, but faster than both of the means at the long ISI. Establishing the most appropriate baseline RT measure in infancy experiments such as this one has proved difficult, with baseline RTs commonly lying outside the range of experimental RTs (Hood and Atkinson 1991). It should also be noted that similar difficulties have been noted in experiments of this kind with adult subjects. Possibly future experiments of this type should involve "double-cue" baseline RT data, rather than the "no-cue" baseline used here.

A second note of caution with regard to the interpretation of the results obtained in this experiment concerns the possibility that the facilitatory effect obtained at the short ISI in the 4-month-old group may be partly attributable to saccades in response to the cue. While studies from other laboratories (e.g. Hood and Atkinson 1991) and pilot studies in our own laboratory had indicated that 4-, and 6-month-olds do not make saccades in response to a 100-ms cue stimulus in the presence of a central fixation stimulus, a post hoc analysis of the data from the present experiment revealed that some 4-month-olds do indeed show evidence of saccades in response to the cue in the 600-ms ISI trials. Specifically in, on average, 26.5 percent of 600-ms ISI trials, 4-month-old infants made an anticipatory saccade (prior to target appearance) toward the cued location. The question arises whether these saccades could have contributed to the facilitatory effect found in the short ISI trials. That is, the infants are faster to respond to the cued target simply because they began their saccade in response to the earlier presented cue. In order to investigate this issue, we defined "cue-triggered" saccades as being those occurring to the cued location during the ISI and within 200-ms of target onset in the 600-ms ISI trials.<sup>8</sup> Note that since any long ISI trial condition with infants leads to a number of trial losses due to looks away from the central fixation point, our criterion for "cue-triggered" saccades is likely to overestimate their frequency by including a few spontaneous looks away from the central screen that happen to be directed to the cued location. Thus, several infants in our sample showed one or more saccades toward the opposite side during the 600-ms ISI.

The first reason it is believed that cue-triggered saccades do not contribute substantially to the facilitatory effect observed is that they tend to be of very long latency. While the mean RTs to make a saccade in the 4-month-old group in this experiment varied between 400 and 550 ms, the mean for cue-driven saccades was 650 ms (standard error 33 ms). One possibility is that this

long RT is a reflection of the fact that the cue stimulus only just exceeds the threshold for eliciting a saccade in these cases. If we subtract the SOA (100-ms cue plus 100-ms ISI), then these cue-triggered saccades would have a mean RT from target onset of 450 ms in the short ISI trials. This mean RT lies between the mean RTs to the cued (400 ms) and uncued (523 ms) targets. Thus, it is apparent that while cue-triggered saccades could contribute to the facilitatory effect, they cannot account for it entirely.

A second approach to assessing the contribution of cue-triggered saccades to the facilitatory effect observed is to take advantage of the fact that some infants in our sample of 4-month-olds showed very few or no such saccades. The results from the 6-infants who showed one or less cue-driven saccade under 700 ms (500 ms after target onset in the short ISI trials) are presented in table 11.3. While these infants showed very few cue-driven saccades (and even these were of such long latency that they would only weaken any facilitation effect), their mean RTs to the cued and opposite targets are virtually identical to those of the whole sample. Further, they show an even stronger preference to orient to the cued side. This post hoc analysis indicates that while the cue does occasionally drive saccades in the long ISI trials, these saccades are not a major contributor to the facilitatory effects observed in the short ISI trials.

The above observations about the relation between cue-driven saccades in the long ISI trials and the facilitation effect at the short ISI trials may be accounted for in the following way. Covert shifts of attention occur in response to the cue. When the target stimuli are presented in the short ISI trials, the earlier covert shift results in facilitation of saccades to that location. In the long ISI trials, however, not only is the ISI longer but so is the time between the central fixation stimulus going off (at the same time as the cue) and the target onset. In some of these long ISI trials, infants spontaneously looked away from the central location prior to target onset, presumably due to the absence of the central fixation stimulus. If covert attention is still directed to the cued location, however, they will tend to look more frequently to that location. By this view then, the cue-driven saccades are not directly driven by the cue but rather are spontaneous saccades that follow the earlier covert shift of attention.

Turning to the inhibitory effects observed in this experiment, it appears that the age when inhibition of return (IOR) can first be demonstrated may be

**Table 11.3** Facilitation Effect in the Short ISI Trials of Infants with Few Cue-Driven Saccades

Mean RT to	Cued Target	Opposite Target	% Preference for Cued Side
Whole sample ( <i>N</i> = 15)	400 ms (S.E. 30)	523 ms (S.E. 40)	64.7 (S.E. 4.0) <sup>a</sup>
Criterion sample ( <i>N</i> = 6)	400 ms (S.E. 43)	537 ms (S.E. 77)	68.0 (S.E. 4.1) <sup>a</sup>

a. Significance at *p* = 0.01 or greater.

dependent on the size of the visual angle between the central fixation point and the cue/target. There is reason to believe that this may be the case since Rafal et al. (1989) showed that IOR is dependent upon the (adult) subjects planning a saccade and infants under 4 months of age commonly show hypometric saccades toward a target (Aslin 1981). Thus, if young infants are not accurately planning a saccade, they may not show IOR.

Harman, Posner, and Rothbart (1992) reasoned that if infants have to make several saccades to a target at 30 degrees' eccentricity, then they will not show IOR at the target destination. This should not be the case for a target at only 10 degrees' eccentricity since this shift of gaze can easily be achieved by one saccade in the very young infant. In accordance with their prediction, Harman, Posner, and Rothbart (1992) found evidence of IOR in 3-month-old infants at 10 degrees but not at 30 degrees. While it is possible that IOR could be found at still younger ages (Valenza et al. 1992), Harman and colleagues argue that its developmental onset is probably linked to the maturation of cortical structures involved in the development of programmed eye movements, namely, the frontal eye fields. Although a visual angle of 29 degrees was used in the present study, the evidence obtained was consistent with the idea that IOR develops at around the same age as facilitatory aspects of covert attention. This may be because both facilitation and inhibition are dependent upon maturation of the frontal eye fields. Later I will argue that the apparent discrepancy between the IOR results reported in this chapter, and the work of Harman, Posner, and Rothbart (1992) and Valenza et al. (1992) may also be accounted for by the fact that covert shifts of attention are used to elicit IOR in the present experiment, whereas infants were allowed to make a saccade to the cue in the other studies.

A final caveat to the conclusion that exogenously cued covert shifts of visual attention develop between 2 and 4 months of age concerns the possibility that the temporal dynamics of facilitation and inhibition vary during infancy. In the present experiment only two ISIs were investigated, 100 and 600 ms. If it had been possible to sample a several other ISI times, the group of 2-month-olds may have shown facilitatory effects between somewhere between 100 and 600 ms, and inhibitory effects at longer gaps. That is, the ISI lengths that produce facilitation of RTs and orienting may become shorter with increasing age. Such a result could reflect slower shifts of covert attention in younger infants. A longitudinal study with multiple ISI lengths is underway in order to resolve this issue.

### **Endogenous Covert Orienting**

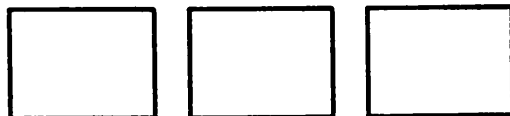
While most of the attention studies in infants have been concerned with exogenous (peripheral) cueing, Johnson, Posner, and Rothbart (1991) attempted to train infants to use a stimulus presented in a central location as a cue to predict the peripheral location (right or left of center) at which a target stimulus would subsequently appear. The sequences of stimulus presentation within trials are illustrated in figure 11.7. This experiment is analogous in some

## Training Trials

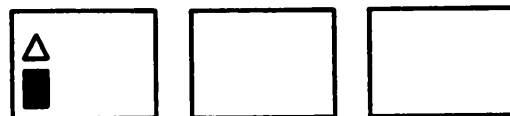
### Fixation Stimulus



### Gap (1 Second)



### Target



## Test Trials

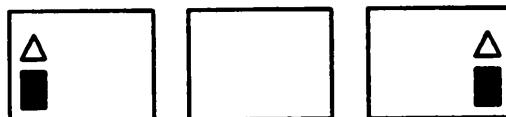
### Fixation Stimulus



### Gap (1 Second)



### Target



**Figure 11.7** The order of stimulus presentation in the experiment of Johnson et al. (1991).

respects to studies in adults in which attention is cued to a peripheral location by means of a central (endogenous) cue such as an arrow. Groups of 2-, 3-, and 4-month-old infants were exposed to a number of training trials in which there was a contingent relation between which of two dynamic stimuli were presented on the central monitor, and the location (right or left of center) where an attractive target stimulus was subsequently presented. After a number of such training trials, we occasionally presented “test” trials in which the target subsequently appeared on both of the side monitors, regardless of which central stimulus preceded it. In these test trials we measured whether the infants looked more toward the cued location than toward the uncued loca-

tion. While 2- and 3-month-old infants looked equally frequently to the cued and opposite sides, 4-month-olds looked significantly more often toward the cued location. This result, taken together with a similar finding in an earlier study (de Schonen and Bry 1987), is at least consistent with endogenously cued shifts of attention being present in 4-month-old infants.

#### **11.4 THE VOLITIONAL CONTROL OF ORIENTING IN EARLY INFANCY**

In the section on overt orienting, evidence was reviewed indicating that saccadic control in the infant goes from being mainly driven by exogenous factors to being primarily under endogenous control.<sup>9</sup> This transition from exogenous to endogenous was not observed in studies designed to measure covert orienting in infants. Rather, results obtained so far are consistent with both exogenous and endogenous cueing of covert attention becoming effective between 2 and 4 months of age. A plausible explanation of this apparent difference between overt and covert orienting is simply that the ability to shift attention covertly is the limiting critical factor in development. That is, under 4 months of age infants show exogenously cued overt orienting but not exogenously cued covert orienting simply because they are unable to shift their attention covertly.<sup>10</sup> Support for this view comes from IOR studies. IOR is associated with exogenously cued shifts of attention. It can also be obtained with infants in experiments in which the cue is presented long enough for infants to make a saccade toward it consistently (overt orienting) (Clohessy et al. 1991). Recent studies that involve overt orienting toward the cue have found evidence for IOR in infants under 4 months of age (Harman et al. 1992), and possibly even in newborns (Valenza et al. 1992). Thus, IOR may be elicited in infants under 4 months but only following overt orienting to a cue.

In the earlier section on overt orienting, I also argued that the onset of endogenous control of eye movements coincided with the development of the frontal eye fields (FEF). In the subsequent section on covert orienting, evidence was presented that infants have the ability to perform covert shifts of visual attention by around the same age, 4 months. What underlying neural events might give rise to this latter development? Both neuroanatomical (Conel 1939–1967) and neuroimaging evidence relating to the postnatal growth of the human cortex suggests that the posterior parietal lobe, a cortical region associated with shifts of covert attention (e.g., Posner et al. 1984), is undergoing rapid maturation around 3 to 4 months of age. For example, results of a positron emission tomography study led Chugani, Phelps, and Mazziotta (1987) to conclude that parietal regions undergo their most rapid period of development between 3 and 6 months of age in the human infant. Thus, while sufficient development of the FEF may be crucial for the endogenous control of eye movements, adequate development of the parietal lobe may be necessary for the ability to shift attention covertly.

Clearly, it would be simpleminded to believe that the functions of the FEF and the parietal cortex are completely independent of each other. Further,



it would also be misleading to describe the onset of functioning in these structures as being an all-or-none phenomenon. It is much more likely that functioning develops in a more graded and coordinated manner. With these considerations in mind, it is interesting to note that there are a number of closed loop circuits that project down from the cortex to the basal ganglia before returning to one of the cortical regions from which they originated (for review, see Alexander, DeLong, and Strick 1986). One of these pathways is commonly referred to as the oculomotor circuit, due to evidence from neurophysiological studies of its involvement in eye movements. It has been proposed that this circuit is crucial for voluntary saccades (Alexander, DeLong, and Strick 1986). The circuit receives projections from both the frontal eye fields and the parietal cortex (as well as from the dorsolateral prefrontal cortex). After passing through a number of subcortical structures such as the caudate and portions of the substantia nigra, it returns to the frontal eye fields. I suggest that the graded development of the cortical components of this circuit is the critical underlying neural event that gives rise to the transitions observed in both overt and covert orienting between 2 and 4 months of age.

What are the implications of these experiments on development for the debate in the adult literature regarding the role of covert shifts of attention in eye movements? The relation between covert shifts of visual attention and the control of eye movements is somewhat complex and controversial in the adult literature (e.g., Klein, Kingstone, and Pontefract 1992; Klein and Pontefract, chap. 13, this volume; Rizzolatti, Riggio, and Sheliga, chap. 9, this volume). While covert shifts of attention and overt orienting (saccades) may be dissociated under some circumstances, several authors have proposed that covert shifts of attention are necessary for, or equivalent to, the planning or execution of saccades (e.g., Rizzolatti et al. 1987). Klein (1980) and Klein and Pontefract (chap. 13, this volume) have presented evidence from endogenous cueing studies in adults against a particular type of relation between overt and covert orienting known as the oculomotor readiness hypothesis: planning an eye movement to a spatial location does not necessitate a shift of covert attention to the same spot. Despite this observation, in many situations covert shifts of attention appear to precede eye movements (Henderson, Pollatsek, and Rayner 1989; Shephard, Findlay, and Hockey 1986; Posner 1980), suggesting that these covert shifts contribute to saccade planning. Following this latter view, we would expect that the ability to shift attention covertly may be a necessary prerequisite for the volitional control of saccades. In development therefore, the endogenous control of saccades should follow, or develop simultaneously with, the ability to shift visual attention covertly. In contrast, note that if we found that the endogenous control of saccades developed significantly before the ability to shift attention covertly, this would support the view that overt and covert orienting are entirely independent. The experiments reported in this chapter indicate that covert shifts of attention (at least as measured by facilitatory effects) and the volitional control of saccades develop around the same age, 4 months, consistent with their being some dependence relation between the two processes.

In conclusion, studying how various components of the visual attention system develop provides a useful supplement to information gained from both normal and brain-damaged adult subjects. In particular, predictions about the sequence of development of components of overt orienting have been put forward on the basis of evidence from developmental neuroanatomy, and some of these predictions have been confirmed. Further, while the investigation of covert shifts of attention in early infancy is at an early stage, the results obtained so far indicate that these processes are present in infants as young as 4 months of age.

## NOTES

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1. The data from infants who fussed, or who failed to look toward the cue for 50 percent or more of the first block of trial, were discarded.
2. Of course, this does not mean that covert shifts of attention are not involved in tasks in which the infant makes a saccade toward the cue, merely that we have no way of establishing that this is the case.
3. However, it is difficult to say whether this effect is due to facilitation or inhibition, or both, for the following reason. Hood demonstrated that in the absence of the central fixation stimulus, the 6-month-olds readily oriented toward cue stimulus. Since the cue had similar visual characteristics to the target stimulus and there was no temporal gap between their presentations, this is functionally the same as keeping the cue stimulus on while removing the central fixation point. In other words, we would expect no difference between the "baseline" RT to orient toward the target in the absence of the cue and the ipsilateral cue trials: the result that was indeed observed (Hood 1993). In short, the lack of a transition between cue and target means that there is little scope for demonstrating facilitatory effects.
4. Recent evidence obtained by Harman, Posner, and Rothbart (1992) and Valenza et al. (1992) that shows evidence of inhibition of return in younger infants will be discussed later.
5. Data from 6-month-olds using the same procedure are currently being collected.
6. The stimulus onset asynchrony refers to the time between the onset of the cue stimulus and the onset of the target.
7. We defined direct saccades as those in which the eyes moved straight from the stimulus to one or other of the targets. Sometimes the younger infants stopped momentarily while on the way to the target. These trials were included as long as the infant reached the target without saccading elsewhere beforehand.
8. Saccades occurring within 200 ms of target onset in infants are commonly classified as "anticipatory" (Haith, Hazan, and Goodman 1988; Johnson, Posner, and Rothbart 1991).

9. Of course, even in the adult, there remain many situations where exogenous saccades can be elicited.
10. This statement is subject to the caveats about the evidence for covert orienting mentioned earlier.

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