Thought Without Language

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Differences between adult and infant cognition: is the crucial variable presence or absence of language?

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How does 'thought without language' differ from 'thought with language'? Do they differ? Do certain cognitive skills or strategies rely on language so that they would be impossible without language?

One way to try to address these questions is to look at infants in the first year of life, who, for the most part, do not have language.[1] Does their thinking differ from that of adults in fundamental ways?

The answer is by no means clear. Infants sometimes seem to show very sophisticated abilities, such as abstraction, generalization, problem-solving, and planning; that is, infants sometimes show behaviours that are analogous to the very highest abilities of which adults pride themselves. On the other hand, bright, mature adults sometimes show the same 'dumb' behaviours seen in infants—e.g. failure to show transfer of training, absence of systematic hypothesis testing or planning, rigidity, and perseveration. Is there no fundamental difference between the way infants and adults think? Or, are analogies misleading so that seemingly similar behaviours are really fundamentally different? When infants do not seem to be able to do something, is it a problem of communication (i.e. it is hard for us to tell them what we would like them to do) or is it a problem of infants' lack of cognitive ability?

My own research suggests that there are important differences in how the mind of the infant and the adult works. That research links some of the developmental changes between 6–12 months of age to maturation of frontal cortex. In fundamental ways, the behaviour of infants below 9–12 months resembles that of adults with frontal cortex damage. Adults with damage of frontal cortex have language, however. Thus, my work suggests that, yes, infants organize experience and action in different ways from adults, but that

[1] It is an interesting, and somewhat open, question how much language infants have below one year. Some infants say their first word as early as eight or nine months, and children understand much earlier than they speak.

this difference may not be due to the fact that adults have language and infants do not.

The hypothesis that developmental changes between 6–12 months might be related to maturation of frontal cortex had seemed plausible because of (a) the similarity of Piaget's AB̄ task (Piaget 1954) to 'delayed response' (DR), and (b) the overwhelming evidence linking DR to frontal cortex function.

Similarity of AB̄ and delayed response

AB̄ is one of the classic markers of developmental change during the second half of the first year of life. An infant watches as a toy is hidden in one of two identical wells, a delay of 0–10 sec is imposed, then the infant is allowed to reach. Infants under 7½ months cannot uncover a hidden object and so cannot be tested on AB̄. Infants of 7½–11 months usually find the toy at the first well (A). When side of hiding is reversed to B, however, they reach back to A (Diamond 1985; Fox *et al.* 1979; Gratch and Landers 1971). Hence the name 'A, not B'. Since the task was originally devised in the 1930s it has been used extensively with infants.

DR is the classic test for prefrontal cortex function in non-human primates. Since Jacobsen first introduced the test for this purpose in 1935, it has been used extensively. In DR, as on AB̄, the subject watches as a desired object is hidden in one of two identical wells,[2] a delay of 0–10 sec is imposed, then the subject is allowed to reach. Within-trial procedures are exactly the same on the two tasks. DR and AB̄ differ only in how side of hiding is varied over trials. In DR, side of hiding is varied randomly; in AB̄ the reward is consistently hidden on one side until the subject is correct, then side of hiding is reversed and the procedure repeated.

The performance of infants from 7½–9 months on AB̄ matches, in considerable detail, that of monkeys with prefrontal cortex lesions on DR. At delays as brief as 1–2 sec, infants fail AB̄ and frontally lesioned monkeys fail DR (*infants:* Diamond 1985; Evans 1973; Gratch *et al.* 1974; *monkeys*: Battig *et al.* 1960; Fuster and Alexander 1971; Goldman and Rosvold 1970; Harlow *et al.* 1952). This is true whether the hiding places differ in left–right location (*infants:* Diamond 1985; Gratch and Landers 1971; *monkeys:* Goldman and Rosvold 1970; Harlow *et al.* 1952) or in up–down location (*infants*: Butterworth 1976; *monkeys*: Fuster 1980). Both groups succeed when there is a 0 sec delay (*infants*: Gratch *et al.* 1974; Harris 1973; *monkeys*: Battig *et al.* 1960; Fuster and Alexander 1971; Goldman and Rosvold 1970; Harlow *et al.* 1952) or when they are allowed to keep looking at, or orienting their body toward, the correct well during the delay (*infants*: Cornell 1979; Diamond 1985; Fox *et al.* 1979; *monkeys*: Battig *et al.* 1960; Miles and Blomquist 1960; Pinsker and French 1967). Both are able to learn to associate a landmark with the correct well, and to use that information to reach correctly even at long delays (*infants*: Butterworth *et al.* 1982; Diamond unpublished thesis, 1983; *monkeys*: Pohl 1973).

Another task closely linked to frontal cortex function is 'spatial reversal'. Here, side of hiding is varied as on AB̄: the reward is always hidden on one side until the subject is correct, then side of hiding is reversed and the procedure repeated. The difference between spatial reversal and AB̄ is that in spatial reversal the subject does not see where the reward is hidden, whereas in AB̄ and DR hiding is done in full view.

Spatial reversal requires the subject to deduce where the reward is hidden on the basis of feedback. Initially, the reward is always hidden in the same place. Animals with frontal cortex damage have no difficulty learning this initial spatial discrimination (e.g. Goldman and Rosvold 1970; Gross and Weiskrantz 1962). However, when side of hiding is reversed frontally operated animals are impaired. They persist in reaching to the previously correct place (e.g. Butter 1969; Butters *et al.* 1969; Goldman and Rosvold 1970; Mishkin *et al.* 1969).[3]

This is very similar to the pattern of performance of infants on AB̄: they are correct at the first place the reward is hidden, but when side of hiding is reversed errors appear; infants persist in reaching to the previously correct place (Diamond 1985; Gratch *et al.* 1974; Harris 1973).

Failure on DR and spatial reversal is the hallmark of lesions to dorsolateral prefrontal cortex. AB̄ appears to be a composite of DR and spatial reversal: identical to DR on within-trial procedures and identical to spatial reversal on between-trial procedures.

Evidence linking delayed response to prefrontal cortex

DR performance in the monkey has been consistently shown to depend upon frontal cortex function by virtually every known anatomical, physiological, and pharmacological technique. Moreover, it has been consistently linked to a specific subregion within frontal cortex, the dorsolateral prefrontal region, the critical locus within that site being the principal sulcus (Butters *et al.* 1969; Goldman and Rosvold 1970). The link between DR and prefrontal cortex was first demonstrated by Jacobsen (1935, 1936), and scores of studies using ablation procedures have replicated the finding that animals fail DR following

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[2] On DR, the subjects have been non-human primates and the desired object, food. On AB̄, the subjects have been infants and the desired object, a toy.

[3] The Wisconsin card-sorting test was designed to be an adaptation of spatial reversal appropriate for human adults (Berg 1948; Grant and Berg 1948). The subject is required to deduce the correct criterion (colour, shape, or number) for sorting a deck of cards on the basis of feedback. Adult patients with frontal lobe damage learn the initial sorting criterion normally but, when the criterion is switched, they are impaired; they persist in sorting according to the criterion that was previously correct (Milner 1963, 1964; Drewe 1974).

bilateral lesions of prefrontal cortex (major reviews include Fuster 1980; Markowitsch and Pritzel 1977; Nauta 1971; Rosenkilde 1979).

Equally large ablations elsewhere in the brain, e.g. parietal cortex, do not produce deficits on DR (e.g. Jacobsen 1936; Meyer *et al.* 1951). Lesions of prefrontal cortex which produce deficits on DR do not produce deficits on other tasks, such as visual discrimination (e.g. Harlow and Dagnon 1943; Jacobsen 1936; Pohl 1973). In short, DR appears to be sensitive to damage specifically to prefrontal cortex, and damage to prefrontal cortex produces deficits only on specific tasks, such as DR.

These results have been replicated with techniques that enable experimenters to interrupt functioning of a localized neural region temporarily and reversibly. Thus DR has also been linked to the frontal lobe using *localized cooling* (Alexander and Goldman 1978; Bauer and Fuster 1976; Fuster and Alexander 1970), *localized electrical stimulation* (Stamm 1969; Stamm and Rosen 1969; Weiskrantz *et al.* 1962), and *localized dopamine depletion* (depleted using 6-OHDA, deficits reversed by L-Dopa) (Brozoski *et al.* 1979).

Inferring function from dysfunction can be problematic. It is important that the link between DR and prefrontal cortex has been confirmed by techniques that assess patterns of functioning in the intact brain: *surface-negative steady potential shifts* (Stamm 1969; Stamm and Rosen 1969), *single unit recording* (Fuster 1973; Fuster and Alexander 1971; Niki 1974), and *2-deoxyglucose metabolic labelling* (Bugbee and Goldman-Rakic 1981).

All of this work taken together, representing as it does such diverse experimental approaches, makes the link between DR and prefrontal cortex essentially incontrovertible.

Since AB̄ and DR are so similar and the evidence so convincingly links DR to frontal lobe function, it was hypothesized that maturation of the frontal lobe might underlie some of the cognitive advances between 6–12 months. This was tested using AB̄, DR, and another task, object retrieval, which, although also linked to the frontal lobe, appears to share little or none of the task requirements seen in AB̄ or DR. (Object retrieval is a transparent barrier task, where the subject must make a detour to reach a visible goal; nothing is hidden.) The line of inquiry involved studying the developmental progression of performance on these tasks in the human infant and infant monkey, the effects of brain lesions on performance of these tasks in the infant and adult monkey, and the relation between developmental progression on these tasks and brain maturation in the infant monkey.

Results with human infants on AB̄

Twenty-five full-term infants (11 male, 14 female) were studied longitudinally, with testing every two weeks from 6–12 months. Another 84 children were tested only once at ages between 6 and 12 months. The testing apparatus

consisted of a table with embedded wells. All subjects were tested individually in the laboratory. An infant was seated on the parent's lap facing the testing table, equidistant from the wells. The experimenter was seated across the table, facing parent and child. A trial began with the experimenter holding up a toy to catch the infant's attention. As the subject watched, the experimenter slowly hid the toy in one of two wells. Particular care was taken to ensure that the subject observed this. Both wells were covered simultaneously, and a brief delay imposed. Subjects were prevented from straining, turning, or looking at a well during the delay. Parents were instructed to look straight ahead and to restrain the infant's arms and torso gently but firmly. Visual fixation of the wells was broken by the experimenter calling to the infant during the delay and counting aloud, which caused the infant to look up. After the delay, the subject was allowed to reach. A reach was defined as the removal of a cover.

Confirming and extending previous work (Fox *et al.* 1979; Gratch and Landers 1971), a developmental progression in AB̄ performance was found in infants between 7½ and 12 months (Diamond 1985). The delay needed to produce the AB̄ error increased continuously at an average rate of about 2 sec per month (see Fig. 13.1). At 7½–9 months, the characteristic AB̄ error pattern occurred at delays of 2–5 sec. By 12 months, infants reached correctly at delays as long as 10 sec.

Although delay remained constant across trials, performance did not.

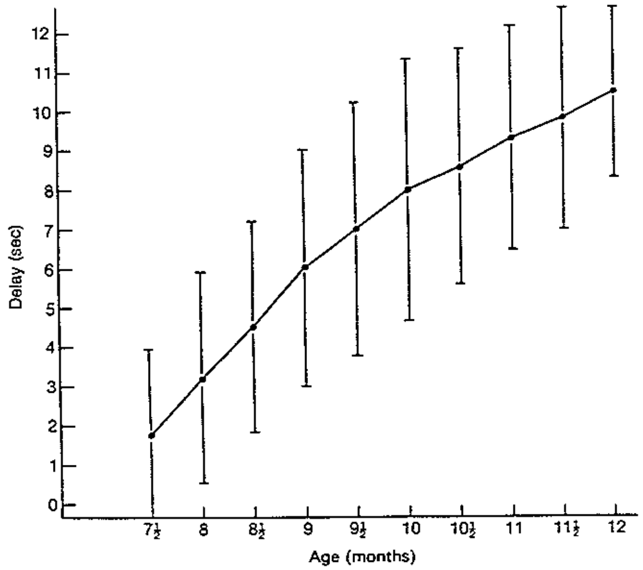


Fig. 13.1 Delay at which the AB̄ occurred by age. (From Diamond 1985.)

Infants erred on only certain classes of trials (reversal trials and repeat trials following errors), while in the same session, at the same delay, they reached correctly on another class of trials (repeat trials following correct reaches) (Diamond 1985). This is the classic error pattern from which the name AB̄ is derived, for infants are correct at 'A' but they are not correct when side of hiding changes to 'B' (see Fig. 13.2).

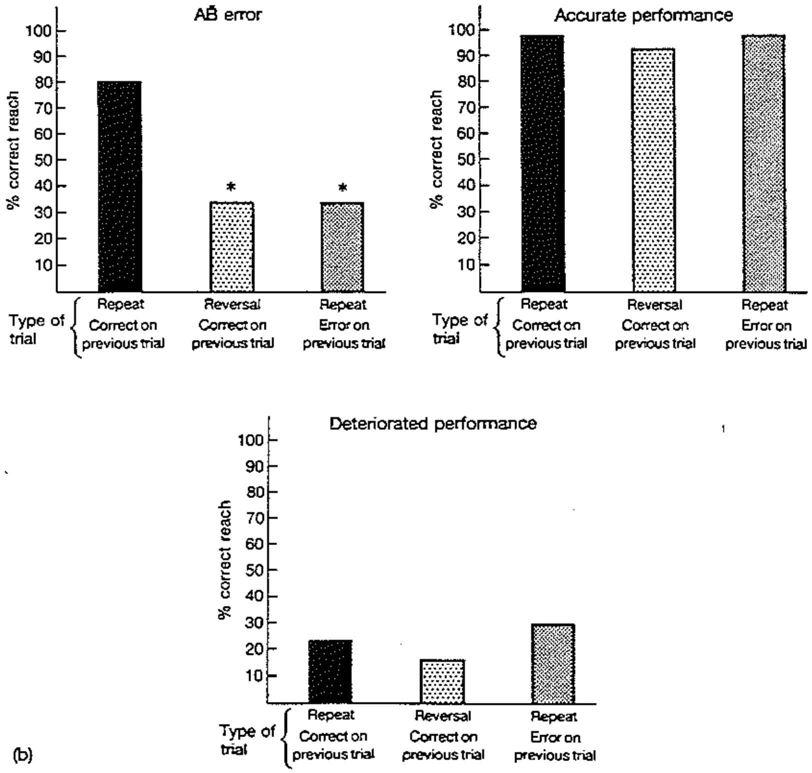
All children made the AB̄ error throughout the months of testing. At each age, errors disappeared when delay was reduced 2–3 sec, and performance deteriorated when delay was increased 2–3 sec above the level producing the AB̄ error. Thus, at 7½–9 months a 10 sec delay produced deteriorated, random performance, with errors equally distributed over trials instead of in the AB̄ error pattern. By 12 months, infants reached correctly even at delays as long as 10 sec.

The AB̄ testing table contained three wells arranged in a semicircle, although only two wells were used on each trial. The wells used were always adjacent and the infant was also seated equidistant from the wells used. The three-well arrangement was needed for testing sequences such as the following: The toy is hidden in the centre well, the centre and left wells are covered, and the infant correctly retrieves the toy from the centre well. Then the centre and right well are covered. If the infant reaches to the centre well that would be a reach to the same absolute position, whereas if the infant reaches to the right well that would be a reach to the same relative position. Infants under 9 months of age always reached to the same absolute position (the centre). That is, they did not consider the wells in relation to one another but only in isolation. After having retrieved the toy from the centre well, they always reached to the centre well, regardless of the other well covered. Starting at 9 months, infants began to consider the wells in relation to one another and began reaching to the same relative position. Preference for the relative position never became predominant in infants from 9–12 months of age but it became as likely as reaching to the same absolute position (Diamond, unpublished thesis, 1983).

Infants in the longitudinal sample, tested every two weeks on AB̄, were 2–4 weeks ahead of infants tested only once. However, the same general

Trial no.	Side hide	Other well	Reach	Type of trial: Repeat trial following correct reach	Type of trial: Reversal trial following correct reach	Type of trial: Repeat trial following error
1	L	C	✓			
2			✓	X		
3	C	L	errs		X	
4			errs			X
5			✓			X
6			✓	X		
7	L	C	errs		X	
8			✓			X
9			✓	X		
	etc.					

(a)



(b)

Fig. 13.2 (a) Types of AB̄ trials. When side hide and other well are the same as on the previous trial, these columns are left blank. ✓=correct reach. Trial 1 is not characterized by type of trial because trial type is determined, in part, by side of hiding and performance on the previous trial. (b) Performance by type of trial for the AB̄ error, accurate performance, and deteriorated performance. A delay 2–3 sec shorter than the delay at which AB̄ error occurs produces accurate performance. A delay 2–3 sec longer than the delay at which the AB̄ error produces deteriorated performance. Note that only during the AB̄ error is there a significant difference in performance by type of trial. (From Diamond 1985.)

developmental progression was found in infants tested cross-sectionally or longitudinally(Diamond 1985, in prep.).

Results with monkeys on AB̄

The same AB̄ task administered to the infants was administered to the monkeys. The only differences were as follows: (1) a testing tray was used rather than a table, (2) food was hidden instead of a toy, (3) visual fixation was broken by lowering an opaque screen rather than by calling to the subject and counting aloud, and (4) monkeys were not physically restrained from moving during the delay (although if they tried to position cue this habit was broken).

Nine adult rhesus monkeys (*Macaca mulatta*) were tested every weekday for 15 weeks (Diamond and Goldman-Rakic 1983). Prior to testing, three animals received bilateral lesions of dorsolateral prefrontal cortex (Broadmann's areas 8, 9 and 10), three received bilateral parietal cortex lesions (Broadmann's area 7), and three were unoperated. All ablations were bilateral, symmetrical, and performed in one stage. The prefrontal and parietal lesions were comparable in size (see Fig. 13.3). A minimum of two weeks was allowed for post-operative recovery.

Six adult cynomologus monkeys (*Macaca fascicularis*) were tested every weekday for 20 weeks (Diamond *et al.* 1987). Three animals received bilateral lesions of the hippocampus, and three were unoperated. All ablations were bilateral, symmetrical, and performed in one stage (for histological description of similar ablations, see Zola-Morgan and Squire 1986). All animals were tested on 'delayed non-match to sample', the criterial test for hippocampal function. The hippocampal animals were severely impaired on this task. AB̄ testing was done many months after surgery; to check for possible recovery of function all animals were retested on delayed non-match to sample after AB̄ testing. The hippocampal animals were as impaired as they had been on first testing.

Four infant rhesus monkeys were studied longitudinally, with testing every weekday from 40–150 days (Diamond and Goldman-Rakic 1986). At the end of testing (4½ months), two of them received bilateral ablations of dorsolateral prefrontal cortex (Broadmann's areas 8, 9, and 10). They were retested on AB̄ at 5 months.

Infant rhesus monkeys of 1½–2½ months, and prefrontally operated adult and infant rhesus monkeys, made the AB̄ error at delays of 2–5 sec, as do 7½–9-month-old human infants (Diamond and Goldman-Rakic 1983, 1986). Although delay was constant across trials, performance differed systematically by type of trial with errors restricted to reversal trials and to repeat trials following errors (see Fig. 13.4). Like 7½–9-month-old human infants, they reached randomly at delays of 10 sec.

Unoperated adult rhesus and cynomologus monkeys, parietally operated

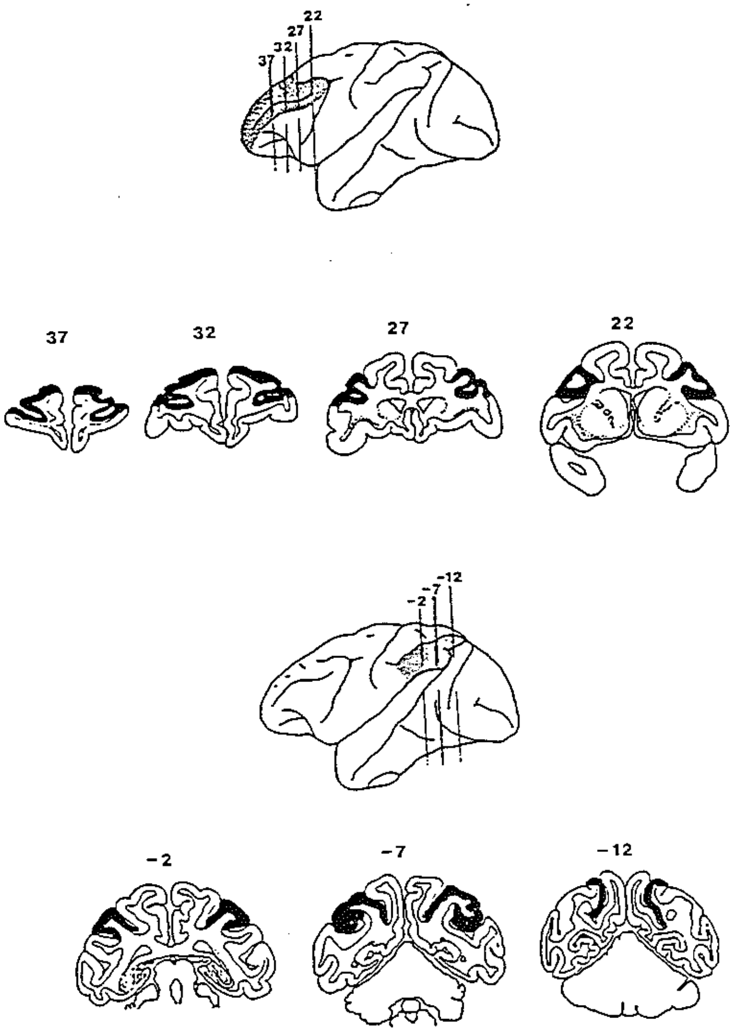
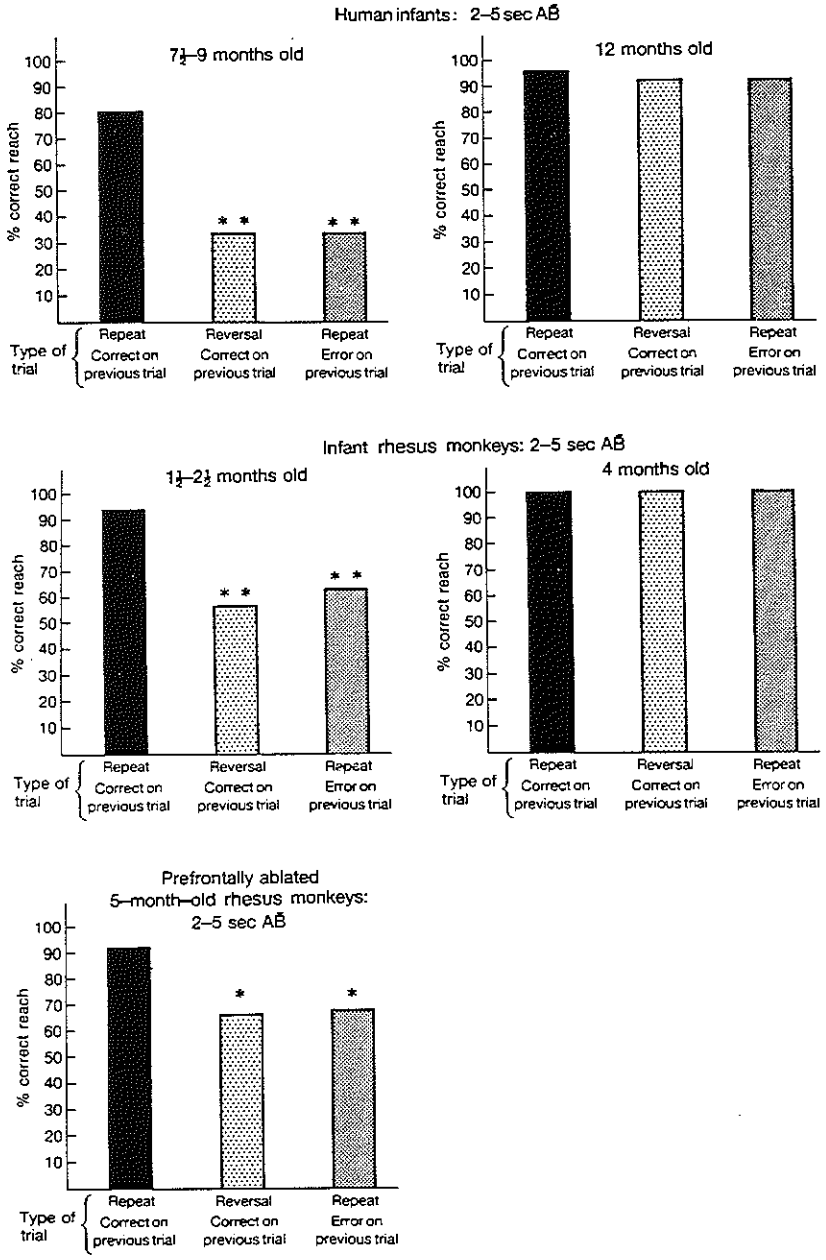
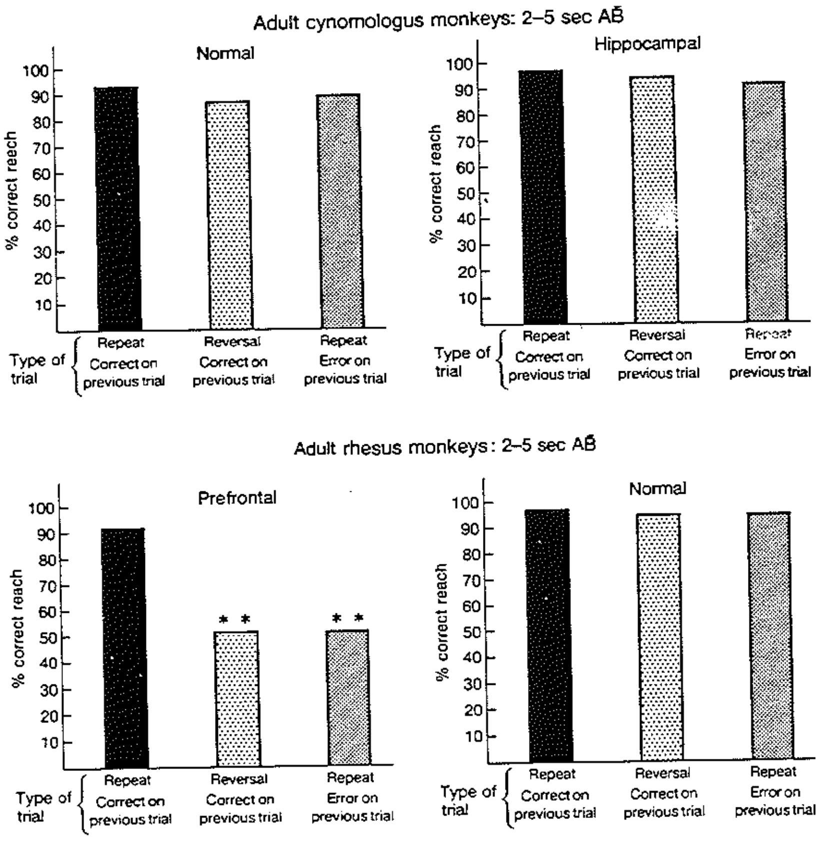


Fig. 13.3 Diagram of cortical ablations, projected on the left hemisphere and in coronal sections. Dorsolateral prefrontal site is shown above and parietal site below. (From Diamond and Goldman-Rakic, in prep.)





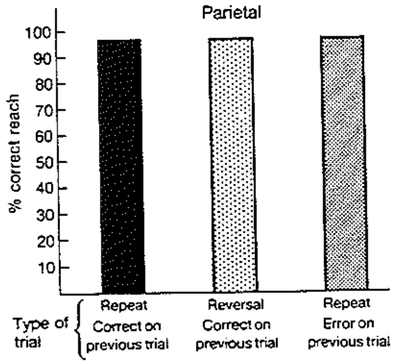


Fig. 13.4 Pattern of performance across trials on AB̄ at delays of 2–5 sec in human infants, infant rhesus monkeys (intact and frontally operated), adult cynomologus monkeys (unoperated and hippocampally operated), and adult rhesus monkeys (unoperated, frontally operated, and parietally operated).

adult rhesus monkeys, hippocampally operated adult cynomologus monkeys, and infant rhesus monkeys of four months reached correctly on AB̄ even at delays of 10 sec (as do human infants of 12 months).

Hippocampally operated monkeys showed impaired performance on AB̄ at delays of 30 sec, but their performance never showed the characteristic AB̄ error pattern.

Thus infant monkeys appeared to show the same developmental progression on AB̄ between 1½–4 months as human infants show between 7½–12 months. The only ablation that produced the AB̄ error was that of prefrontal cortex; lesions of parietal cortex and of the hippocampus did not produce this effect. Ablation of prefrontal cortex had the same effect on AB̄ performance in the infant as it did in the adult, suggesting that the aspect of prefrontal function required by AB̄ matures during infancy.

Results with human infants on delayed response

Twelve full-term infants (six male, six female) were studied longitudinally, with testing every two weeks from 7–12 months (Diamond and Doar, in prep.). Another 40 children were tested only once at ages between 8–12 months. The testing apparatus and procedure were the same as that used for AB̄ with human infants, except that side of hiding was varied randomly over trials by a predetermined schedule. A testing session consisted of 16 trials. Criterion for correct performance was 14 correct reaches (88 per cent).

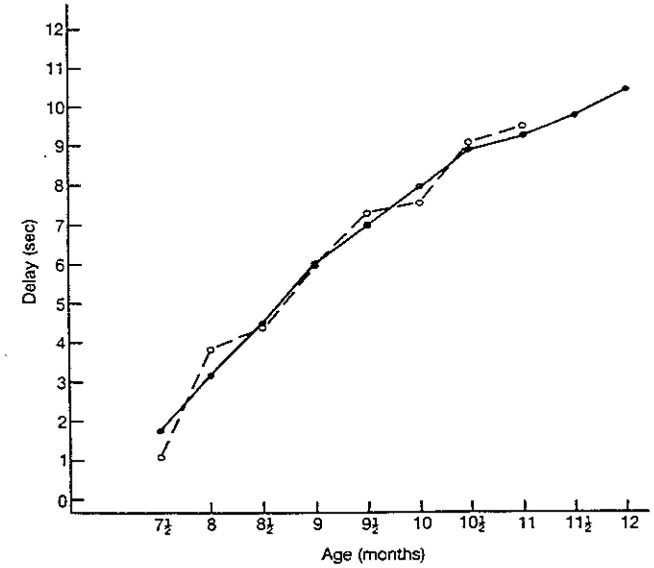


Fig. 13.5 Delay at which performance on DR in human infants was below criterion by age, superimposed over the delay at which the AB̄ error occurred by age. Criterion on DR=88 per cent correct (at least 14 of 16 trials correct). Dash line=DR. Solid line=AB̄. (From Diamond and Doar, in prep.)

The developmental progression for DR performance is given in Fig. 13.5, superimposed over the developmental progression for AB̄ performance. The curves are virtually identical, even though AB̄ testing was done at Harvard University with babies from the Boston area, DR testing was done at Washington University with babies from the St Louis area, different testers administered AB̄ and DR, and the DR testers were blind to the earlier AB̄ results. In all respects, the results for DR are comparable to those for AB̄: (a) excellent performance on repeat trials following correct reaches; errors confined to reversals following correct reaches and repeat trials following errors; (b) infants tested only once lagged 2–4 weeks behind infants tested longitudinally, but the form of their performance was the same; (c) large individual differences between infants of the same age; and (d) boys lagged 2–4 weeks behind the girls.

This completes the AB̄-DR story. Monkeys with prefrontal cortex lesions perform on AB̄ as do 7½–9-month-old human infants. Human infants of 7½–9 months fail DR under the same conditions as do monkeys with lesions of prefrontal cortex. The performance of human infants on DR mirrors their performance on AB̄.

Results with human infants on object retrieval

'Object retrieval' (OR) is a detour task with the goal object inside a rectangular box open on one side. Three Plexiglas boxes were used for human infant testing: (a) transparent, 6″ × 6″ × 2″, (b) transparent, 4½″ × 4½″ × 2½″, and (c) opaque, 4½″ × 2½″ × 2½″.

As with AB̄, all subjects were tested individually in the laboratory. Each infant was seated on the parent's lap facing the testing table and experimenter. A trial began with the experimenter placing a toy in one of the boxes. The infant had simply to retrieve the toy. No time limit was imposed. A trial ended with retrieval or when the infant refused to try any longer. Considerable freedom of movement was permitted and, if an infant became distracted, the experimenter tapped the box or toy to regain attention. The experimenter held the back of the box throughout each trial to prevent the infant from simply lifting the box off the toy.

Experimental variables included: (a) side of box which was open (front, top, left, or right), (b) distance of toy from opening (ranging from partially outside the box to deep inside the box), and (c) position of box on the testing surface (near front edge of table or far; far to the left, at the midline, or far to the right). The bait was always visible when a transparent box was used, but the experimental variables jointly determined whether the toy was seen through a closed side of the box or through the opening. Order of conditions was counterbalanced across testing sessions.

The idea for OR came from a task on which Moll and Kuypers (1977) had demonstrated impairments in monkeys following lesions of the frontal lobe:[4] food could be seen beneath the centre of a transparent floor plate, but the only route to the food was through a hole in the plate's side. Monkeys with frontal lobe lesions only reached straight for the food at the centre of the plate, although normal monkeys and those with lesions elsewhere had no difficulty making the appropriate detour. When a unilateral frontal lobe lesion was combined with a commissurotomy, the hand contralateral to the lesion persisted in reaching at the plate's centre, while the hand connected to the intact hemisphere *of the same monkey* reached through the hole to the food!

The same 25 infants tested longitudinally on $A\bar{B}$ were tested on OR during the same bi-weekly sessions. The 84 children in the cross-sectional sample were tested on both $A\bar{B}$ and OR in the same session (Diamond 1981).

Infants were found to pass though a clear, tightly age-related series of phases in the performance of OR. All infants progressed through the same sequence of phases, in the same order, at approximately the same age (see Fig. 13.6). So rarely did infants deviate from this that the sequence of development fits a Guttman scale with a coefficient of reproducibility of 0.93. There was a small effect of repeated testing (infants in the cross-sectional sample lagged approximately 2–4 weeks behind infants tested longitudinally), but the same phases were found in the same order.

Infants of $6\frac{1}{2}$–7 months, like the monkeys with frontal lobe lesions studied by Moll and Kuypers (1977), were unable to retrieve the reward if they saw it through a closed side. They banged and scratched with considerable effort and persistence, but if their line of sight did not change they tried no other route to the toy. They insisted on reaching directly to where they saw the toy. The tendency to be guided only by visual information was so strong that it overrode available tactile information and the effect of repeated reinforcement. This is impressive because we know that infants at this age, and younger, will react to tactile information and we know that their behaviour can be shaped by reinforcement (e.g. Lipsitt *et al.* 1966; Rovee-Collier and Fagan 1981). So totally controlled was their reach by their line of sight that a fraction of an inch difference in the height of the box or in how close the box was to the baby made the difference between success and failure—everything depended upon whether the infant was looking through the opening. Even if an infant's hand was already inside the box *en route* to the toy, if line of sight changed the infant withdrew the hand and reached to the side through which he now saw the toy.

The first advance on OR was seen at $7\frac{1}{2}$–8 months. It was a small change and

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[4] The lesions were large, extending from dorsolateral prefrontal cortex into supplementary motor and premotor cortex, terminating in the rostral part of the precentral gyrus.

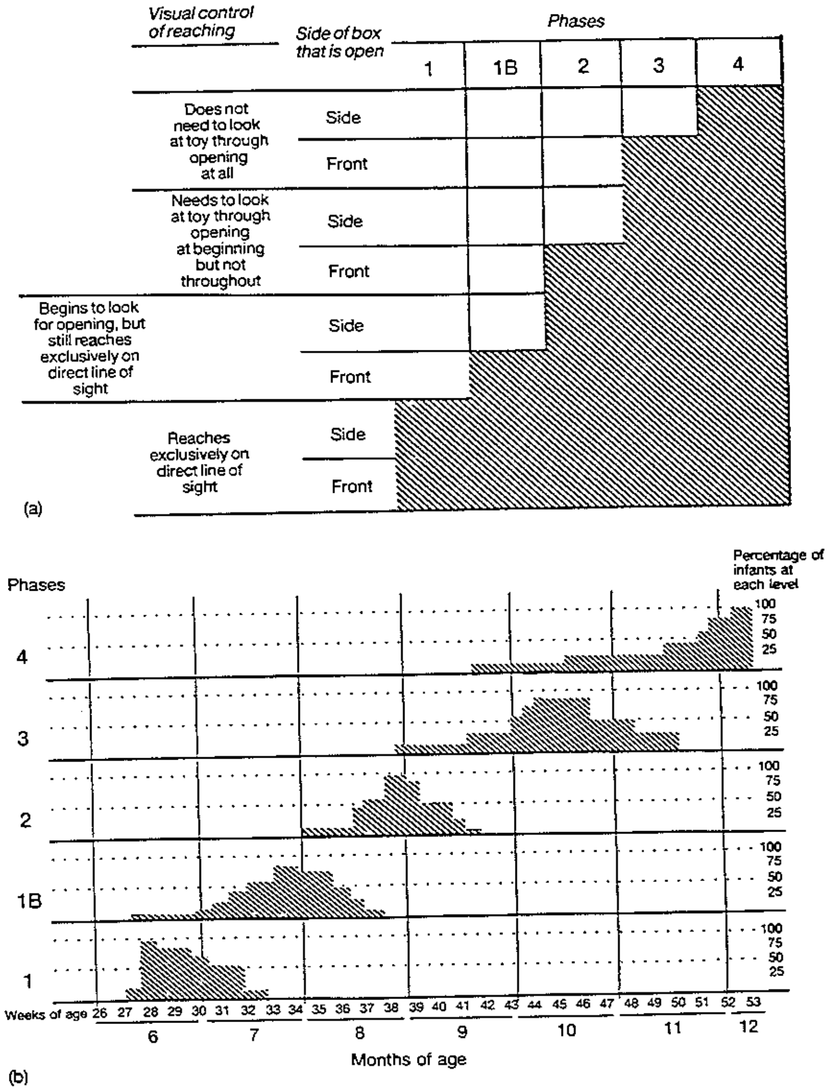

Fig. 13.6 (a) Characterization of the phases in performance of OR. (From Diamond 1981.) (b) Histograms of the age distributions for the OR phases. Based on performance with the transparent box by the 25 infants studied longitudinally. (From Diamond 1981.)

so is called phase 1B, rather than phase 2. The advance is that infants, for the first time, took active steps to look at the toy through different sides of the box, (e.g. leaning to look through a different side of the box or moving the box). However, $7\frac{1}{2}$–8 month-old-infants still reached only at the side of the box through which they were looking. When line of sight changed, the reach changed too. Onset of phase 1B coincided almost exactly with when infants could first uncover a hidden object (see Table 13.1). Phase 1B and uncovering an object require a more active, or less passive and reactive, orientiation than is seen in younger infants. This marks the first time infants take an active step to change the situation with which they are presented.

The means–end behaviour seen here is quite rudimentary. For example, infants were permitted to raise the front of the box (with the experimenter holding the back of the box down on the table) so that the front opening of the bottomless box became quite large and the infant could see in. Often, a $7\frac{1}{2}$–8-month-old infant would raise the front of the box with both hands, remove one hand from the box, and attempt to reach for the toy, but the box would come down halting the reach. The reach would halt and go back to the box top because once the box was down the infant saw the toy through the box top rather than through the open front, and reaches were made at this age only at the side through which the infant was looking. But why did the box come down; after all, the second hand was still holding on? The problem here was that when the infants lowered one hand to reach for the toy, they had great difficulty *not* lowering the other. They would repeatedly try to raise the front of the box, but the hand left to hold up the box repeatedly failed at its task. With both hands in the raised position, when one was lowered, the other came down too.[5]

Table 13.1 *Age at which the 25 infants studied longitudinally entered Phase 1B on OR and could first uncover a hidden object. (Five infants were not yet ready for A$\bar{B}$ testing with two wells when they could first uncover a hidden object.) Note the striking similarity in age of entering Phase 1B and age of onset of A$\bar{B}$ error*

Age (in weeks) of first appearance of:	Phase 1B, object retrieval	Able to find totally hidden object, one hiding place	A$\bar{B}$ error
Jack	35 (3) =	35 (3)	37 (5)
Lyndsey	33 (2) =		33 (2)
Tyler	36 (2)		38 (4)
Jamie	34 =		34
Emily	34 (2) =		34 (2)
Rachel	32 (4)		30 (6)
Brian	28 (3) =		28 (3)
Ryan	33 (1) =		33 (1)
James	28 (5)	28 (5)	30 (5)
Erin	30 (3)		32 (4)
Sarah	34 (6) =		34 (6)
Julia	33 (2) =		33 (2)
Mariama	34		36 (3)
Kate	31 (6)		33 (5)
Rusty	35 (6)		33 (5)
Todd	39 (4) =		35 (1)
Nina	31		29
Isabel	32 (5) =		32 (5)
Jennine	31 (4) =	31 (4)	33 (2)
Jane	34 (5) =		34 (5)
Bobby	33 (2) =		33 (2)
Graham	34 (2) =		34 (2)
Blair	35 (4) =	35 (4)	37 (3)
Michael	34		36 (4)
Chrissy	32 (6) =	32 (6)	34 (4)

At $8\frac{1}{2}$–9 months (phase 2), the first separation of line of sight and line of reach occurred. Infants leaned and looked through the front opening of the box, sat up, then reached into the front while looking through the top of the box. For the first time, the memory of having looked into the opening was sufficient. For the first time, infants could look through one side and reach through another. (This is reminiscent of Millar and Schaffer's (1972, 1973) finding on an operant conditioning task requiring infants to push a lever in order to see a light display. Even 6-month-old infants succeeded when the lights and lever were in the same visual field, but not until 9 months could they look one place and reach another.) If an infant had not looked into the opening on that trial, he would still not reach there, but having looked in, line of sight through the opening no longer needed to be maintained.

At $8\frac{1}{2}$–9 months, the problem of raising the box was also solved sequentially. The infant first raised the box, both hands came down, and then the infant reached in and retrieved the toy.

Between phases 1 and 4 there was an explosion in the number of sides of the box to which infants reached. Whereas $6\frac{1}{2}$–7-month-old infants often reached to only one side of the box throughout a trial, an $8\frac{1}{2}$–9-month-old might show the following sequence of reaches over a trial: front, top, left, front, top, left, front, top, front, top, front, top, left, top, right opening. Infants no longer restricted themselves to one side of the box, but, going to the other extreme, made many more reaches than necessary. They kept returning to sides of the box to which they had already reached and found closed.

Performance with the opening at the left or right of the box always lagged one phase behind performance at the front. Hence, at $8\frac{1}{2}$–9 months, infants showed phase 1B performance when the opening was on the left or right of the

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[5] A similar observation was made by Bruner (1969). Here the task consisted of a box with a transparent lid mounted on sliding ball bushings. To retrieve the toy, the child had to slide the lid up its track, which was tilted 30° from the horizontal and would fall back down if not held. 'A seven month old has great difficulty holding the panel with one hand while reaching underneath with the other. Indeed, the first compromise solutions to the problem consist of pushing the panel up with both hands, then attempting to free one hand in order to slip it under the panel. One notes how often the infant fails because the two hands operate in concert' (Bruner 1969, p. 222).

box: they leaned and looked in the opening and needed to maintain this line of sight during the reach. This leaning and looking to the left or right was accompanied by an 'awkward reach', i.e. a reach with the hand contralateral to the opening. Reaching thus with the hand farthest from the opening made the action maximally contorted and awkward.

By 9½–11 months (phase 3), infants succeeded when the front of the box was open without looking into the opening at all. They were able to raise the box with one hand and reach in with the other, or raise the box with both hands, lower one hand, and *keep the box raised* with the other. When the opening was on the left or right side of the box, 9½–11-month-old infants still needed to look in the opening, but they could then sit up, look through the top, and reach through the side. Awkward reaches disappeared.

Four of the 25 infants followed longitudinally departed from the typical picture of phase 3. They reached to the left- or right-side opening *without* first looking in through that side. However, these four infants all failed to get their hand inside the opening. They misreached, going too high or too far, etc. For example, one child kept getting her thumb stuck on the top edge of the opening. To try to help her out, the experimenter tipped the box to enlarge the size of the opening, but then she reached much higher yet and still got her thumb stuck on the top edge of the opening! It was as if, although most infants appeared to attend only to vision, ignoring available tactile information, these four infants attended only to touch, ignoring the available visual information. They seemed to search for the opening the way a blind person would, by feeling for the edge. Therefore, when the opening was made very large, they still went for the edge.

Finally, by 11–12 months (phase 4), infants were perfect on OR. They did not need to look in the opening on any side to succeed. Their performance was efficient, quick, and accurate. Number of sides of the box to which infants reached returned almost to the low levels seen in phase 1, not because they reached to only one side of the box as did phase 1 infants but because one-year-old infants rarely returned to a side to which they had reached and found closed. A single touch, or look, sufficed to tell them whether a side was open or closed. They attended to both visual and tactile information. They would reach simultaneously to different sides of the box, and whichever was open they would enter. Younger children, too, reached with both hands, but typically both of their hands reached to the same side; now the hands were used to get two different pieces of information.

To determine side preferences, all infants tested on AB̄ and OR were also presented with five pairs of identical objects. A similar age progression is seen here. By 12 months, infants often reached simultaneously for both objects. Younger infants almost never did so. When younger infants used both hands they reached with both hands for the same object (Table 13.2).

Once infants were old enough to retrieve a hidden object (approximately 7½ months) they were also tested with an opaque box. At each age, performance was one phase ahead on the opaque box compared with the transparent box (Diamond 1981). Thus, when infants could not see the toy at the outset of trial, they performed *better* than when they could. Bruner *et al.*, (unpublished manuscript, 1969) and Lockman (1984) report similar results with an opaque wall vs. a transparent wall. This counterintuitive finding that the task was easier when infants could not see their goal can be understood in light of the fact that when the box was opaque infants did not need to resist reaching along their line of sight; they could not see the toy through the box.

Table 13.2 *Percentage of simultaneous reaches for both objects when presented with five identical pairs of objects*

Age (months)	% reaches for both objects
5	0
6	3
7	7
8	18
9	21
10	28
11	44
12	61

Based on the 25 infants studied longitudinally.

Testing on both OR and AB̄, thus, yielded clear age-related patterns of improvement over a rather brief time period in all children. Although OR and AB̄ are quite different tasks, improvement on each occurred over the same age range. Since different experiences would seem to have been necessary for mastery of these quite different tasks, the fact that improvement on both is seen over the same age period suggests that these improvements are, at least in part, maturationally based.

Results with monkeys on object retrieval

The same OR task administered to human infants was administered to rhesus and cynomologus monkeys. These were the same animals tested on AB̄. The only differences in OR procedure were: (1) food was placed in the box instead of a toy, and (2) the experimenter held the box in place by a locking device hidden underneath the testing surface instead of by holding onto the back of the box. The Plexiglas boxes used with adult monkeys were: (a) transparent, 5″ × 5″ × 2″, and (b) transparent, 3″ × 3″ × 2½″. The Plexiglas box used for infant monkey testing was transparent, 3″ × 3″ × 2½″.

Adult rhesus monkeys with prefrontal lesions and infant rhesus monkeys of $1\frac{1}{2}$–$2\frac{1}{2}$ months showed the same pattern of performance on OR as did $7\frac{1}{2}$–9-month-old human infants (phases 1B and 2) (Diamond and Goldman-Rakic 1985, 1986). No monkeys displayed phase 1 behaviour as they all actively tried to look through more than one side of the OR box. Whereas human infants below $7\frac{1}{2}$ months rather passively accepted the task as presented, infant monkeys of even $1\frac{1}{2}$ months moved quite a bit. (Monkeys below the age of $1\frac{1}{2}$ months cannot reach and retrieve a piece of food and so cannot be tested on OR). Monkeys are more advanced at birth than are humans and very shortly become quite mobile and agile.

Human infants of $7\frac{1}{2}$–9 months, frontally operated monkeys, and infant monkeys of $1\frac{1}{2}$–$2\frac{1}{2}$ months all needed to have seen the bait through the opening of the box in order to reach in and retrieve it. When the bait (toy for children, food for monkeys) was partially out of the box they reached for it straight away, but, if in so doing they accidentally pushed the bait inside the box, they could no longer retrieve it. Deserting the opening, they tried to reach through the transparent wall of the box through which they now saw the bait, even though they had pushed the bait inside the box themselves (see Fig. 13.7)!

Frontally operated adult animals and $1\frac{1}{2}$–$2\frac{1}{2}$-month-old infant monkeys also reached repeatedly to sides they had tried and found closed like human infants at phase 2 on OR. Their approach to the problem appeared more frantic than systematic.

Monkeys with frontal lobe lesions and infant monkeys of 2–$2\frac{1}{2}$ months also showed the 'awkward reach': they reached to the left side of the box with their right hand and to the right side of the box with their left hand, seeming to make the task maximally difficult for themselves (see Fig. 13.8).

In contrast, human infants of 11–12 months, unoperated adult rhesus and cynomologus monkeys, parietally operated adult rhesus monkeys, hippocampally operated adult cynomologus monkeys, and 4-month-old infant rhesus monkeys succeeded on all trials straightaway. They did not need to have looked through the opening and they reached into the left or right side effortlessly with the hand nearest the opening (see Fig. 13.9). A single touch served to tell them whether a side was open or closed; they did not persist at a closed side and did not return to sides already tried and found to be closed.

Thus, infant monkeys appeared to show a similar developmental progression on OR between $1\frac{1}{2}$–4 months as do human infants between $7\frac{1}{2}$–12 months. In the monkey this progression was truncated, however. Human infants progressed through stages 1, 1B, 2, 3, and 4. Infant monkeys progressed from stage 1B–2 to stage 4. Consistent with the more rapid post-natal development of the monkey, this progression took 5–6 months in humans but only 2–3 months in the monkey.

On the surface, OR and A$\bar{\text{B}}$ appear to share little in common. OR is a detour task, where the bait is always visible. In A$\bar{\text{B}}$ the bait is hidden. However, the

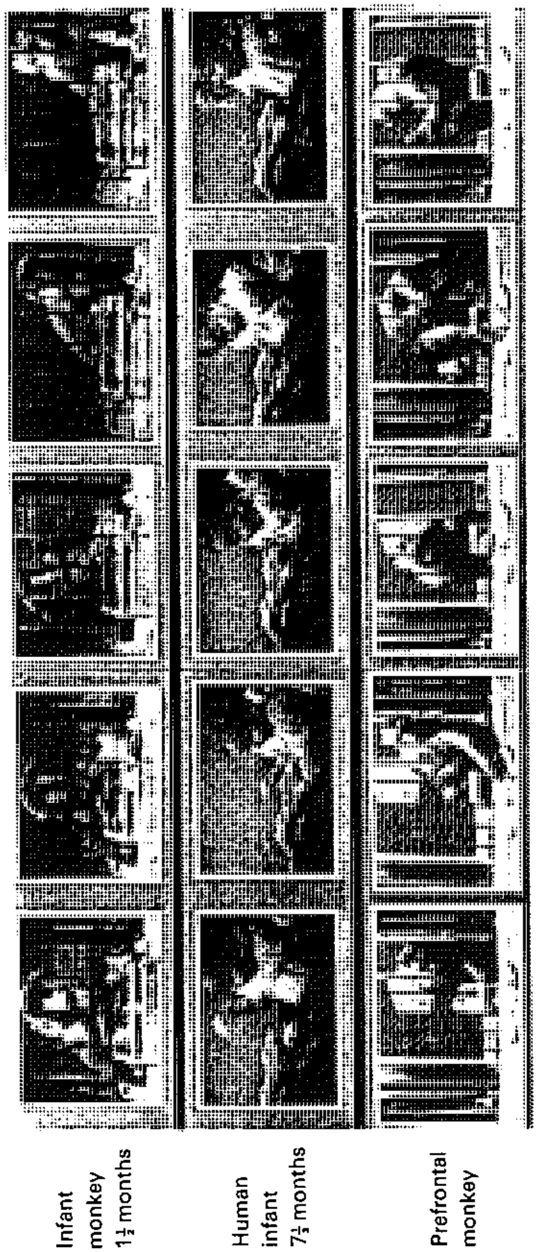

Fig. 13.7 Failure after pushing the toy inside the box themselves. Frame 1: Bait is partially out of box, S reaches immediately for the part that is sticking out of the box. Frame 2: S accidentally pushes bait into the box. Once bait is inside the box, S is unable to retrieve it, even though S was touching the bait. Frame 3: S withdraws hand from opening and goes to the side of the box through which he sees the bait. Frame 4: S looks at bait through front of box and reaches to the front. Frame 5: Unable to retrieve the bait, S gives up. (From Diamond and Goldman-Rakic 1985).

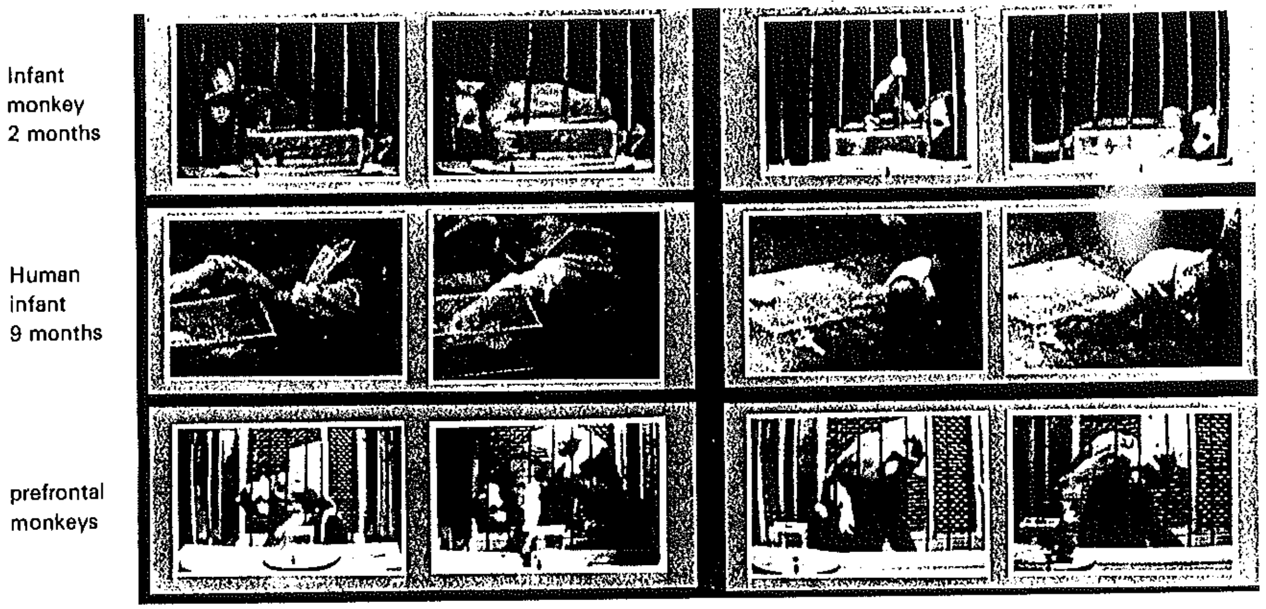

Fig. 13.8 The awkward reach. Frame 1: S leans and looks at bait through opening of box. Frame 2: S reaches in awkwardly with the far hand. Frame 3: Opening is on the other side. Performance is the same. S leans and looks into the opening. Frame 4: S reaches in awkwardly with the far hand. (From Diamond and Goldman-Rakic 1985.)

Fig. 13.9 Mature performance. Frame 1: S reaches to opening with near hand without leaning and looking in opening. Frame 2: S retrieves bait quickly and efficiently. Frame 3: Opening is on the other; performance is the same. S looks through top of the box and reaches into opening with the near hand. Frame 4: Success!

fact that human and simian infants improve on both tasks over the same period and the fact that both tasks have been linked to the frontal lobe suggests that they probably require common abilities.

Abilities required by AB̄ and object retrieval: insights from the function subserved by the frontal lobe

In what ways are the behaviours of infants below 9–12 months described above similar to the behaviours of adults with frontal lobe damage? What do these behaviours suggest about how the mind of an infant or a frontal lobe patient differs from that of a normal adult?[6]

AB̄ and DR have usually been thought to be measures of memory or perseveration (e.g. *memory*: Fox *et al.* 1979; Jacobsen 1936; *perseveration*: Bremner and Bryant 1977; Mishkin 1964). However, neither of these interpretations works very well for OR. OR does not appear to require memory as the box is transparent. Instead of infants perseveratively repeating what they did on the previous trial, they *fail* to repeat the previous trial's performance if a change is made in the variables controlling line of sight. For example, following three successful retrievals from the *front* of the box, if the box is moved forward 1 inch and the toy moved ½ inch deeper into the box (so that the infant now sees the toy through the top), infants below 8½ months reach only at the top of the box on this trial, although the perseverative response would be to reach at the front. Infants fail by not repeating their previous response (Diamond 1981). Thus, if a common explanation is to be sought for AB̄ and OR performance, it must be something other than forgetting or perseveration. Two general abilities are proposed: (a) relating information over space or time, integrating two or more pieces of information, and (b) inhibition of predominant action tendencies.

Relating information separated in space or time

OR requires the subject to relate the box opening to the bait over a spatial separation. When bait and opening are superimposed (as when the bait is in the opening, partially out of the box) even the youngest infants and prefrontally operated monkeys succeed. However, as the spatial separation between bait and opening widens, the age at which infants succeed progressively increases.

AB̄ requires the subject to relate two *temporally* separated events—cue and

response. The subject watches as a bait is hidden in one of two identical wells, a brief delay follows, then the subject is allowed to reach. When there is no delay between hiding and retrieval even the youngest infants and prefrontally operated monkeys succeed. However, as the time interval between hiding and retrieval increases, the age at which infants succeed progressively increases. Here, memory is conceived as one aspect of the ability to relate information over a separation.

The development of the ability to relate or integrate two or more items is an ever-present theme in the age progression in OR performance. It is seen in the development of the ability (a) to reach through one side of the box while looking through a different side, (b) to attend to both visual and tactile information, and (c) to do different things with the two hands. When infants reach through the side they are looking, they can almost always reach the toy by a straight route. When they look through one side and reach through another, their reach is almost always two-directional, as when an infant sits up and looks through the top and then reaches away from the midline to get to the left or right opening and then directs the reach back toward the midline to get the toy. Here one sees the development of the ability to integrate two movements in opposing directions (see Fig. 13.9 above).

Frontal patients are impaired on delayed comparison tasks where they must indicate whether a test stimulus is the same colour or sound as a target stimulus presented seconds before. They are not impaired, however, when no delay is imposed (Prisko, cited in Milner 1974). This is very reminiscent of results with infants on AB̄.

Tasks that require the simultaneous use of multiple facts prove very difficult for adults with frontal cortex damage. For example, they can solve mathematical problems such as: 'What is 30 divided by 2?' and 'What is 15 times 5?' But they cannot solve: 'If the price of two packages is $30, what is the price of five packages?' (Barbizet 1970). Frontal patients also have unusually severe difficulty doing two things at once or attending to more than one thing at a time. When they are shown a pictorial scene suggesting a story, they typically fixate on one detail in the picture, missing the suggested story (Nichols and Hunt 1940).

Relating items in a sequence is also a problem. An expert cook, following frontal lobectomy, can still measure, pour, sift, and knead, but may not be able to put the ingredients together to bake a loaf of bread or to make a multi-course meal. Frontal patients have great difficulty keeping track of a temporal sequence. They can remember which of two pictures they saw before (unlike temporal lobe patients who cannot), but they cannot remember which of two pictures they saw most recently (Corsi, cited in Milner 1974). When shown a page of words or pictures and instructed to touch all stimuli, one at a time, in any order, but without repeating a choice, frontal patients touch some stimuli more than once, never managing to touch them all (Petrides and Milner 1982). They do not perseverate; rather they simply fail to sample all stimuli

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[6] When normal, mature adults are distracted, stressed, rushed, or exhausted, they make the same errors as do infants and frontal patients. The abilities mediated by the frontal lobe are fragile and the first to go with physical or psychological insult. If something is terribly important to an infant or to a frontal patient and they try very hard, they can sometimes avoid these errors. Thus, the differences between infants and adult frontal patients, on the one hand, and normal adults, on the other, appear to be differences of degree rather than fundamental differences of kind; e.g. normal adults are less likely to make certain errors, but they are not totally immune to them.

systematically. This is reminiscent of the behaviour of 8–9-month-old infants who fail to systematically check all sides of the box; they reach back repeatedly to sides they have tried and found closed.

Inhibiting prepotent responses

In OR, the tendency to reach straight to a visible target must be inhibited. Subjects must instead reach around to the opening. Results when the box is opaque provide particularly strong evidence here: infants performed better with the opaque box, where the toy could not be seen through a closed side. When the toy could be seen through a closed side, there was a very strong tendency to reach there. The opaque box presented no such conflict, because the toy could only be seen through the opening.

Inhibition is also required when infants raise the front of the OR box and then try to lower one hand to reach in, while the other hand holding onto the box remains raised. Problems inhibiting their eagerness and enthusiasm for the toy may also contribute to why infants do not approach the task more systematically. Schaffer *et al.* (1972) report that, although infants of at least 6 months indicate visually (through habituation and dishabituation of looking) that they can tell whether or not they have seen an object before, until 9 months of age they reach impulsively for all objects. At 9 months, behavioural inhibition to the novel appears, i.e. the latency to reach for a new object becomes significantly longer than the latency to reach to the familiar.

In AB̄, a conditioned tendency or 'habit' to reach to 'A' (where the subject was rewarded) must be inhibited when the bait is hidden at 'B'. Indeed, infants may sometimes reach back to 'A' on the AB̄ task even when they know the toy's location, because of difficulty inhibiting this habitual response. Thus, even when the toy is *visible* at B, errors sometimes occur, as when the covers are transparent, and occasionally when there is no cover at all (Butterworth 1977; Harris 1974). Often, infants will uncover A, *not look in*, then reach immediately to B and retrieve the toy (Diamond 1985). It is as if they know the toy is at B even though they reach first to A. Most telling, occasionally an infant will look directly at B before, and throughout, the reach, even as that infant's hand goes to A.[7] If visual fixation were the dependent measure, the infant would be scored as correct on such trials (see Fig. 13.10).

This is reminiscent of the performance of frontal patients on the Wisconsin card sort: after being rewarded for sorting the cards by one criterion, frontal patients have difficulty sorting the cards by a new rule. However, these patients can sometimes tell you the new rule as they continue to sort the cards incorrectly. Indeed, they sometimes say, as they are sorting the cards by the old criterion, 'This is wrong, and this is wrong. . .' (Luria and Homskaya 1964; Milner 1964; Nauta 1971).[8] Infants cannot tell you the correct answer verbally, but looking at A even as they reach to B may be the non-verbal equivalent. Improved performance may mark the emergence of the ability to resist making the predominant response, the emergence of the ability to exercise choice.

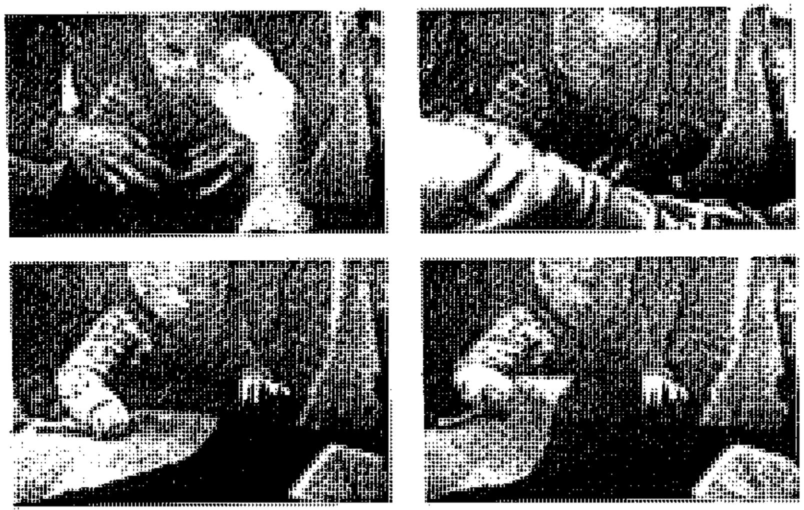

Fig. 13.10 Instance of an infant looking at B while reaching to A. Infant had successfully retrieved toy at A. Side of hiding is now reversed to B. Top row: Infant clearly sees the hiding. Following a brief delay, he was allowed to reach. Bottom row: Although infant is looking fixedly at B, his hand goes back to A.

In AB̄ and the Wisconsin card sort, an initial response is strengthened by reinforcement. This effect of reinforcement on a response is evident in infants soon after birth (Sameroff 1971; Rovee-Collier 1986) and in the simplest organisms (e.g. Kandel 1979). It is early developing (in phylogeny and ontogeny) and robust, capable of surviving considerable neurological insult. A more fragile and later developing ability is the capacity to *resist* a

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[7] This is a rare occurrence because looking and reaching are usually closely tied in infants. However, it has been observed in many different laboratories and when it occurs it is particularly impressive because such dissociation of looking and reaching is so rare.

[8] Such dissociations between frontal patients' verbal and motor behaviour are common. One such example is provided by Teuber: '[The patient] has in many ways what people call a classical frontal lobe syndrome. . . . He was put to work in the garden where he was assigned to another man who was digging ditches; our patient had a big pair of shears with which to cut roots. . . . And while a ditch was opened, a huge thing appeared; four black strands lying side by side. The patient was standing there, and the subsequent episode was described by both the patient and his companion. He said, 'Ha ha, it's not a root. It looks like a root (going through the motions of cutting). It looks like a root. It's not a root. Why are the fire alarms ringing?' By cutting the strands he had shorted out all the cables that led to the alarms all over the camp' (Teuber, in discussion of Konorski and Lawicka 1964, pp. 287–288).

predominant response, whether it is innately strong or has been strengthened by reinforcement. It is this ability that is required when the correct well changes in AB̄ or the correct criterion changes in the Wisconsin card sort. Although instinctual and habitual responses are very strong, even in humans, we are capable, with effort, of breaking a habit, whereas organisms without frontal cortex may have no such option. The ability to resist the strongest response of the moment endows humans with extraordinary flexibility and freedom to choose and control our actions. It gives us the option of not being creatures of habit.

Adults have yet to be tested on OR or a similar task, but there is evidence that vision exerts a pull on the behaviour of frontal patients similar to that seen in infants. Vision exerts a strong pull in all of us (e.g. Rock and Harris 1967), but most of us with intact frontal lobes are able to inhibit or counteract this tendency when necessary. For example, when asked to hold up a finger when the examiner makes a fist, most of us might be tempted to copy what we see but would manage to follow the instructions. A frontal patient, on the other hand, upon seeing the fist, makes a fist, even though he may repeat the instructions back correctly (Luria 1973). A standard task requires a patient to hold up two fingers when the examiner holds up one finger, and to extend a single finger in response to the examiner's two. Patients with frontal damage cannot resist mimicking what they see and so fail the task (for other examples of echopraxia, see Luria 1966).

This can also be seen in tasks that do not involve vision. For example, although instructed to give a long squeeze to a short tone and a short squeeze to a long tone, frontal patients match the duration of the squeze to the tone, even though they can repeat the instructions correctly (Marushevskii 1959, cited in Luria 1966).

Problems in the inhibitory control of behaviour occur in all areas of life for frontal patients. Socially, they are 'disinhibited', meaning that they lack the usual inhibitions about saying or doing inappropriate things (such as talking about sex in public). Frontal patients are easily distracted by irrelevant, but firmly established, connections. They are pulled by this free association or that. This makes it extremely difficult to obtain even a simple personal history from such patients because of the many associations to that history.

Frontal patients are also especially sensitive to proactive interference.[9] It is as if earlier occurrences are not properly inhibited or damped down. On the delayed comparison tasks of Prisko mentioned above, frontal patients could perform well if trial-unique stimuli were used. However, when stimuli recurred over the trials (so that subjects had to remember whether they had seen a stimulus on the current trial or a previous one), frontal patients were impaired.

This is reminiscent of the AB̄ error: on trials at B infants are unable to inhibit proactive interference from the trials at A.

One of the classic tests diagnostic of frontal lobe function is the Stroop test. Here, the names of colours are printed in the ink of another colour (e.g. the word 'blue' is printed in red ink). Patients are instructed to report the colour of the ink as they look through the list of words. The customary response when reading, however, is to ignore the ink and attend to the meaning of the word. Frontal patients fail the test; they recite the words and not the colour of the ink (Perret 1974).

Problems of inhibition are often problems at the output end. Instead of reflecting deficits in thinking, they reflect deficits in gaining control of one's behaviour so that it reflects what one is thinking. Infants and frontal lobe patients give some indications that they know more than they can often express in their behaviour. Frontal patients give such indications verbally; infants do so with their eyes. We have seen this in AB̄ and in the work of Schaffer *et al.* (1972). It can also be seen in an elegant habituation–dishabituation experiment by Baillargéon *et al.* (1985). Using looking, rather than reaching, as their dependent measure, Baillargéon *et al.* demonstrated that 5-month-old infants appear to know that an object hidden behind a screen is still there. Yet, it is not until at least 2 months later that they will reach behind a screen for a hidden object or will uncover an object. Using reaching as their indicator, investigators had concluded that infants below 7½ months did not know that a hidden object continued to exist. Baillargéon *et al.*'s work suggests that infants know the object is there but cannot use this to guide their reaching behaviour.

Visual habituation is an automatic response, whereas lifting a cover to get what is underneath would seem to require more explicit planning. As discussed earlier, infants below 7½–8 months react automatically and unreflectively to their world. Thus, for example, I would predict that infants younger than 7½–8 months should succeed at delayed non-match to sample but would fail delayed *match* to sample at the same delays, using trial-unique stimuli for each. In both of these tasks, the subject is first shown a model, a delay follows, then the subject is given a choice of an object that matches the model or another object. By the age infants can first reach for an object (5–6 months) they show a reliable preference for the new over the familiar (e.g. Fagan 1970; Fantz 1964; Rose *et al.* 1982). Delayed non-match to sample (which rewards reaching for the non-match) would capitalize on infants' natural tendency to reach to the new, provided they can remember what they have already seen. Delayed match to sample (which rewards reaching to the match), however, would require infants not only to remember what they have seen, but to inhibit their natural tendency to reach to the new stimulus.[10] This combination of requirements (memory plus inhibition) depends, I suggest,

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[9] Sensitivity to proactive interference has been associated with amnesia, but that is only because many amnesics also have frontal lobe disorders. Moscovitch (1982) has elegantly shown that amnesics without frontal symptoms show normal release from proactive interference, whereas frontal patients without amnesia are abnormally sensitive to proactive interference.

[10] It is critical that trial-unique stimuli be used because when the same stimuli are used over trials no stimulus is new, i.e., unfamiliar.

upon frontal cortex, and will be beyond the ability of infants below 9–12 months of age.

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14

Animal spatial cognition

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The theoretical problem of comparing man and animal is frequently tackled in articles about cognitive mechanisms and animal intelligence (cf., for example, d'Amato and Salmon 1984; Premack 1979; Weiskrantz 1985), whereas the characteristics of the 'natural' situations met by both are rarely discussed. This point goes beyond the mere question of methodology and deserves to be highlighted, at least in terms of spatial cognition. In natural conditions, animals live and have to move about in extremely difficult environments, in contrast to the 'assisted' situations that constitute human beings' everyday life, at least in our Western civilizations. Let us imagine a world with restricted possibilities of communication with other people, without any maps, road signs, or tourist offices, in short, without any information transmitted by language or writing. Such is the animal's universe, which may also contain hostile elements such as predators. Therefore, an accurate localization of the nest or burrow, of the places abounding in food, etc., are prerequisites for survival. For these reasons, paradoxical though they may seem, the animal offers us a better model than the human in the study of the cognitive mechanisms involved in spatial orientation. Spatial intelligence is becoming increasingly unnecessary in man, and, according to the laws of evolution, it should be extinct in a few thousand years!

But, what is animal cognition? This psychological concept is vague and has a multiplicity of meanings. According to Neisser (1976, p. 1), 'Cognition is the activity of knowing: the acquisition, organization and use of knowledge'. In fact, apart from describing the initial phases of information-processing, the term usually refers to the ultimate and more elaborated phase of representations.

As we will see later, both phases are closely interdependent, the information-processing being controlled by representations. A cognitive activity is possible without any previous abstraction, however, and the result of cognitive processing may not always be stored and represented.

The nature of what is represented is another factor of differentiation. For example, the information necessary to perform an oriented complex displacement can be stored and represented as a list of instructions or as responses to a