Development of the Ability to Use Recall to Guide Action, as Indicated by Infants' Performance on A$\bar{B}$

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DIAMOND, ADELE. *Development of the Ability to Use Recall to Guide Action, as Indicated by Infants' Performance on A$\bar{B}$*. CHILD DEVELOPMENT, 1985, **56**, 868–883. 25 infants were tested every 2 weeks on the A$\bar{B}$ Object Permanence Task devised by Piaget, from the age when they first reached for a hidden object until they were 12 months. The delay between hiding and retrieval necessary to produce the A$\bar{B}$ error increased continuously throughout this period at an average rate of 2 sec/month, from under 2 sec at 7½ months to over 10 sec by 12 months. All children displayed the A$\bar{B}$ error repeatedly over the months of testing. Large between-children differences in delay needed for the A$\bar{B}$ error were found at each age. Girls tolerated longer delays than boys. The characteristic pattern to the A$\bar{B}$ error did not vary over age or sex. Range of delay producing the A$\bar{B}$ error in any child was small. Errors disappeared when delays were reduced by 2–3 sec, and reaching became random or severely perseverative when delays were increased 2–3 sec above the level producing A$\bar{B}$ error. A$\bar{B}$ provides an index of the ability to carry out an intention based on stored information despite a conflicting habitual tendency.

In Piaget's A$\bar{B}$ Stage IV Object Permanence Task, the infant watches as the experimenter hides a toy in one of two identical wells. A brief delay follows. Then the infant is allowed to reach. Infants usually reach correctly at the first place the toy is hidden (A), but when the side of hiding changes to B, they reach back to A, even though the hiding is performed in full view, they clearly want the toy, and all trials are performed in the same manner at the same delay. This pattern of reaching is called the "A$\bar{B}$ error."

The present study investigates the developmental progression between 6 to 12 months of the ability to withstand longer delays on A$\bar{B}$. Kagan (1974) has suggested that increases in the delay necessary for the A$\bar{B}$ error with age might indicate increases in short-term recall memory with age. The kind of memory involved is recall because once the wells are covered stimulus conditions are the same on all trials. The A$\bar{B}$ task, however, is not a simple test of memory. Success at A strengthens the tendency to reach to A. In addition to recall ability, A$\bar{B}$ requires the ability to resist repeating the previously reinforced response. Taxing either ability alone can produce errors: Simply imposing a delay will produce errors, even on trials at A. Some infants still reach back to A when they can see the toy at B (see results with transparent covers, and no covers, e.g., Bower, 1967; Butterworth, 1977; Harris, 1974). However, few infants err on A trials even with a delay, and few infants err on B trials when the toy is visible. To produce errors, both abilities must usually be taxed, as on trials at B when the toy is out of sight and a delay is imposed. Improvement in A$\bar{B}$ performance with age indicates the development of the ability to use recall to guide action in the face of an ac-

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quired tendency to do otherwise. It indicates the beginnings of the ability to be guided by intention rather than habit.

Method

Subjects

Twenty-five infants (14 female, 11 male), located through the Boston birth records, served as subjects. They were tested on A$\bar{B}$ from the age when they first reached for a hidden object until 1 year. Eighty-five percent of the parents contacted agreed to participate. Parents were informed of the study's general objectives, were given $3 for each testing session, and received a report of the major findings.

Two criteria were used to select infants for study: (1) the infant should be full-term and have no major health problems, and (2) the infant should be unable to find a hidden object, enabling us to observe behavior in the A$\bar{B}$ situation from the earliest point possible.

Of the original 28 infants (14 female, 14 male) selected for 6 months of biweekly testing, only three infants dropped out. All did so early in the study, for reasons of a death in the family or job relocation.

All 28 infants came from intact homes. Only six of the infants had older siblings. Most came from upper-middle-class homes, but a few came from poorer backgrounds and neighborhoods. One boy and one girl were black. Many were Catholic (28%) or Jewish (18%). The average age of the fathers was 31 years, and of mothers 30. Most mothers had worked at some time, but only six continued to work after the baby's birth.

Apparatus

The A$\bar{B}$ apparatus stood 68.75 cm high, 87.5 cm long, and 37.5 cm wide. Embedded in its top were three wells, each 9.38 cm in diameter and 7.5 cm deep. The wells were 27.5 cm apart, center to center. To equalize accessibility of each well to both hands, the wells were arranged in an isosceles triangle, with the center well at the apex and the base of the triangle closer to the baby, in a manner similar to that used by Butterworth (1975). The apparatus was brown, with each well bordered by red tape. Only two wells (left and center or right and center) were covered on any trial. Light blue cotton cloths (22 cm × 22 cm) served as the covers. These cloths held little intrinsic interest for the infants and were easy for them to remove.

Procedure

Each infant was tested individually in our laboratory every 2 weeks. No infant was tested if sleepy or irritable (more than once a parent was asked to return the next day). All sessions were recorded on videotape from behind a one-way mirror.

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 large collection of toys (including keys, rattle, teddy bear, small green car, and others) was available so the experimenter could find a toy that was attractive to each infant. If interest in a toy flagged, the experimenter substituted another toy.

The experimenter signaled the beginning of a trial by holding up a toy and asking the parent to restrain the baby's hands and body gently but firmly. The experimenter then hid the toy slowly in one of the wells. If the infant looked away while the toy was being hidden, the infant's attention was recaptured and the hiding repeated. If the infant looked away again, another toy was substituted and the trial begun anew. Immediately after the toy was placed in a well, the experimenter covered the two wells simultaneously.

With the covering of the wells, the delay period began. Parents were asked to look straight ahead during the delay and to release the infant's hands as soon as the experimenter said "okay." The experimenter counted aloud during the delay to make the infant look up. The counting also reduced the fussing that infants often display during the delay.

In most studies of A$\bar{B}$, infants are not prevented from straining, turning, or staring toward the correct well during the delay. In the present study these behaviors were prevented because of evidence that bodily orientation and visual fixation can be used to simplify the task (Cornell, 1979; Fox, Kagan, & Weiskopf, 1979). A verbal distractor was used to disrupt visual fixation, rather than an opaque screen (as in Fox et al., 1979), because many infants become alarmed by the dropping of a screen, while counting is less distressing yet equally effective in diverting gaze. It should also be noted that when infants are restrained it is impossible to have absolutely no delay between hiding and retrieval. Delays referred to here as "0" sec were actually 0.2–0.5 sec in duration.

A reach was defined as the removal of a cover. A "reach" was not scored if an infant began to reach toward a cover but withdrew his or her hand before touching it, or touched a cover but did not remove it. If, on the other hand, an infant reached to one well, uncovered it, and then immediately reached to another well without looking into the first, the infant was credited nevertheless with reaching to the first well.

A correct reach was rewarded by praise, and even applause, in addition to receipt of the toy. When infants reached incorrectly, they were allowed to continue searching until they gave up or found the toy, but on such trials they were not permitted to play with the toy. If, despite subsequent searching, the infant did not find the toy, the experimenter showed the infant where the toy had been hidden, but did not permit the child to play with it. (Most investigators have allowed the infant to play with the toy after each trial, independent of whether the infant reached correctly or not—e.g., Evans, 1973; Goldfield & Dickerson, 1981; Gratch & Landers, 1971; Harris, 1973. In the present study, reward was made contingent on correct response to maximize motivation to reach correctly and to minimize the possibility that the infant was playing a different game from the one intended.)

Infants were scored as making an error if (1) they reached to the empty, covered well; (2) they did not reach at all; (3) they reached simultaneously to two wells; or (4) they reached to the third, uncovered well. Errors 2–4 were uncommon, with error 4 being particularly rare. Separate analyses were performed using only errors of type 1, and including all errors; results were the same. In the results reported below, errors 1–4 are pooled except where otherwise noted.

Initial side of hiding (well to relative left or right of other well) was counterbalanced across children and visits, and each well (left, center, and right) was used as the toy's initial hiding place on an equal number of visits for each child.

The median number of trials per session was 15, and side of hiding was reversed three to five times within a session. On reversal trials, the same two wells were used, but the toy's location was reversed. No reversal trial was administered until the infant had reached correctly on the trial prior to the reversal.

Most studies of A$\bar{B}$ reverse the toy's location only once. Thus, one well serves as "A," the toy's initial location, and the other well serves as "B," the toy's later location. However, in the present study, where the toy's location is reversed several times, the meaning of A and B becomes unclear. On the second reversal, for instance, B serves as the initial well and A serves as the new hiding place. Therefore, different terms are used to designate trials. A$\bar{B}$ trials are divided into three categories, illustrated in Table 1, based on (*a*) whether side of hiding is the same as on the previous trial or reversed, and (*b*) whether the subject was correct on the previous trial or not. The three categories of trials are: (1) *repeat trial, following correct reach:* the subject reached correctly on the preceding trial, and the bait is again hidden in the same well; (2) *reversal trial, following correct reach:* the subject reached correctly on the preceding trial, but the bait is now hidden in the other well; and (3) *repeat trial, following error:* the subject reached to the wrong well on the preceding trial, and the bait is again hidden in the same well. Note that trials of type 1 differ from each of the other two types of trials in one variable only.

Coders were trained for a period of 2–4 weeks to score the videotape records of the sessions. They were not apprised of the experimental hypotheses, and were trained to be conservative in their judgments. Formal training ended when a coder demonstrated an average reliability, across all items, of $r = .90$ or better with the trainer. Reliability was assessed once each week for as long as coding continued. The lowest intercoder reliability coefficient for any item discussed here is .85; the average is .92.

Experimental Design

Two considerations constrained choice of experimental design: (1) one or two trials are insufficient to determine if an infant is making the A$\bar{B}$ error, and (2) if several trials are to be used at each delay, no infant will tolerate testing at all delays within a given session. Therefore, if a wide range of delays was needed to produce the A$\bar{B}$ in infants of 6–12 months, different children would have to be tested at different delays. Delay was incremented over sessions using performance on the preceding two sessions as an initial guide. If performance on the previous session had been at or above the 90% level, then it was estimated that the delay should be incremented 2–3 sec on the present session to produce the A$\bar{B}$ error. If an infant had committed the A$\bar{B}$ error at the same delay on the preceding two visits, delay was also incremented 2–3 sec. Otherwise, the same delay as on the preceding visit served as the initial estimate of the delay at which the A$\bar{B}$ error would occur.

This estimate was checked at the outset of the testing session. If an infant was correct at the initial hiding place and on the first re-

TABLE 1

HYPOTHETICAL $A\bar{B}$ TESTING SESSION ILLUSTRATING TYPES OF TRIALS

				TYPE OF TRIAL		
TRIAL No.	SIDE HIDE	OTHER WELL	REACH	Repeat Trial, Following Correct Reach	Reversal Trial, Following Correct Reach	Repeat Trial, Following Error
1.[a]	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.						

NOTE.—Side Hide = where toy is hidden; Other Well = other well used (i.e., covered) on that trial; L = left well, C = center well, √ = correct reach.

[a] Trial 1 is not characterized by type of trial, as trial type is determined, in part, by performance on the preceding trial.

versal trial, delay was incremented 2–3 sec. Testing began again, starting at the new hiding place. If the infant still made no errors at the initial hiding place or on the first reversal trial, delay was incremented a further 2–3 sec. Formal testing then began. On the other hand, if the infant reached incorrectly on more than one trial before a reversal was even administered, delay was decreased 2–3 sec and testing restarted. If the infant again erred more than once at the initial hiding place, delay was decreased a further 2–3 sec. Formal testing then began. On sessions where delay was adjusted once or twice, trials at the initial delay(s) are not included in the analysis of $A\bar{B}$ performance; only trials at the delay at which complete $A\bar{B}$ testing was conducted are included.

Because every child was not tested at every delay on every session, one might wonder if observed between-children differences in the delay associated with the $A\bar{B}$ error were somehow artificially produced by the experimenter. To offset this criticism, the range of delay that would produce the $A\bar{B}$ error in a given child was tested. If the range of delay were small, as pretesting indicated, the experimenter would not be free to select duration of delay arbitrarily; differences in the delay producing the $A\bar{B}$ error in different children would have to reflect real differences between the children themselves.

It was hypothesized: (1) If infants who are making the $A\bar{B}$ error at a given delay are tested at a delay 2–3 sec *shorter*, they will stop erring. (2) If infants who are making the $A\bar{B}$ error at a given delay are tested at a delay 2–3 sec *longer*, their performance will deteriorate, with the number of errors increasing and their reaches becoming random, no longer conforming to the pattern characteristic of the $A\bar{B}$ error.

To test these hypotheses the "$A\bar{B}$ error," "accurate performance," and "deteriorated performance" were operationalized. Criteria for the $A\bar{B}$ error were: (1) On at least one trial where side of hiding is reversed, the subject should reach back to the previous hiding place. This is the crux of the $A\bar{B}$ error: when side of hiding is reversed, the subject errs. To reduce the likelihood that this was a chance event, one of the next two criteria had to be met as well: (2) This error should be repeated on the next trial, or (3) the subject should err on at least one more reversal trial during the same session. If errors occur with equal frequency on all types of trials, the subject is reaching randomly. However, if errors occur on specific trials only, in the face of otherwise accurate reaching, then the subject is committing the $A\bar{B}$ error. Hence, criterion 4 below provides an important baseline from which to view performance when side of hiding is changed: (4) Each time the subject is correct, if that trial is repeated unchanged, the subject should again be correct. If, in any given session, a subject made more than one error over all repeat trials, following correct reaches, the subject was considered to be performing below the criterion for the AB̄ error.

Criterion for accurate performance was no more than one error across all trials (performance at the 90% level or better). Criteria for deteriorated performance were: (*a*) at least two errors on repeat trials, following correct reaches (violates criterion 4 for the AB̄ error), and (*b*) performance at or below the 50% level. Performance at this level is usually accompanied by at least one of the following: distress and fussing, refusal to reach, and/or long perseverative error strings.

Three tests were conducted of the effects of an incremental change in delay within a session on performance. For each test, half the trials in a session were given at one delay and half at a delay differing by 2–3 sec. Predictions were made of the effect of a change in delay, that is, of performance during the second half of each session.

During each of these half-sessions, the basic AB̄ testing procedure was followed: three or four reversal trials were administered, and no reversal trial was given until the infant had reached correctly on the previous trial.

Number of trials and number of reversal trials (reversal trials being most likely to elicit errors) were kept as equal as possible across half-sessions. However, half-sessions could not be exactly equal on both dimensions because reversal trials were not administered until the infant had reached correctly. At longer delays, infants made more errors. More trials occurred, therefore, before a reversal could be given. When infants made fewer errors, fewer trials were needed to administer the same number of reversals. Rather than making conditions exactly equal along one dimension, but very unequal along the other, the decision was made to try to equalize simultaneously on both, realizing that neither would be perfectly equal. This solution was two-pronged.

First, number of reversal trials was allowed to vary from three to four. This meant that tests at shorter delays tended to have four reversal trials, and tests at longer delays tended to have three reversals. The prediction, however, was that infants would make few errors at short delays and many errors at long delays. Giving more reversals at shorter delays should, if anything, have biased the results against that prediction.

Second, number of consecutively correct reaches was varied from one to three before administering a reversal. With longer delays, a reversal trial was more often administered after one or two correct reaches. With shorter delays, a reversal tended to be administered after two or three correct reaches. This helped to equalize total number of trials. Evidence indicates that number of consecutively correct reaches preceding a reversal does not affect performance on the reversal trial (Butterworth, 1977; Diamond, 1983; Evans, 1973). If it were to have any effect, it should again have been counter to the prediction, since more consecutively correct reaches prior to reversals were administered at shorter delays, yet fewer errors were predicted there.

Test 1.—All 25 subjects received one test session where half the trials within that session were at a delay that should produce the AB̄ error, and half the trials were at a delay 2–3 sec *shorter*. Order of delay presentation was counterbalanced across subjects and within sex and age groups to control for practice effects, fatigue, and boredom. For purposes of this test, subjects were divided into five age groups (≤36 weeks, 37–40 weeks, 41–44 weeks, 45–48 weeks, 49–52 weeks). Predictions were: (*a*) For infants making the AB̄ error during the first half-session, decreasing the delay by 2–3 sec will produce accurate reaching during the second half-session; (*b*) for infants showing accurate reaching during the first half-session, increasing the delay by 2–3 sec will produce the AB̄ error during the second half-session.

All subjects could not be administered Tests 2 and 3. Limits of time and infant attention permitted only one test per session. The number of sessions per child available for testing the effects of a change in delay was limited to two by the need to use other sessions to test other hypotheses, such as the role of motivation, the role of relative versus absolute spatial coding, and the effect of different covers. Therefore, 10 infants were assigned to Test 2 and 15 infants were assigned to Test 3.

Test 2.—Five infants were randomly selected from the 13 who had received the shorter delay first in Test 1. Similarly, five infants were randomly selected from the 12 infants who had received the AB̄ error delay first in Test 1. These 10 infants, in an entirely different testing session, were retested with order of delay presentation reversed from what that child had previously received. Hence, Test 2 consisted of taking a subset of 10 children and counterbalancing for order of delay presentation within subject, whereas Test 1 had counterbalanced only across subjects.

Test 3.—The 15 infants not given Test 2 were administered Test 3. On one testing session per child, for these 15 infants, half the trials within that session were at a delay that should produce the A$\bar{B}$ error, and half the trials within that session were at a *longer* delay. Order of delay presentation was counterbalanced across subjects and within age and sex groups. The age groups were ≤ 38 weeks, 39–43 weeks, and 44–48 weeks. Within each age category, at least two subjects were male and two female. Eight infants received the delay appropriate for the A$\bar{B}$ error first, and seven received the longer delay first. Predictions were: (*a*) for infants making the A$\bar{B}$ error during the first half-session, increasing the delay by 2–3 sec will produce deteriorated reaching during the second half-session, and (*b*) for infants showing deteriorated reaching during the first half-session, decreasing the delay by 2–3 sec will produce the A$\bar{B}$ error during the second half-session.

It should be noted that all tests were intended to study a 2-sec increase or decrease in delay, not 2 or 3 sec. However, in verifying the actual length of delay from the videotape records, it was discovered that almost half of the changes were 3 sec, not 2. Delay changes of 2 versus 3 sec were not statistically different in effect, and are therefore pooled.

Results

None of the results reported here can be accounted for by side preferences; a tendency to reach to a particular well; differences in motivation for the toy over trials, over sessions, or between children; number of reversal trials per session; number of consecutively correct reaches prior to reversals; or demographic differences between the children. Coders were instructed to answer several items to check for biases introduced by the experimenter or the parent, such as, "Did the experimenter finish covering one well after the other?" and "Did the parent look at any well at any time from the start of the delay until the child reached?" No results are due to possible experimenter or parent biases. Coders verified that infants looked directly at where the experimenter was hiding the toy on over 99% of the trials.

Parents had been instructed to hold their infant's arms and torso tightly to minimize the infant's ability to strain or turn toward the correct well during the delay. As this did not eliminate straining altogether, the effect of bodily orientation on performance was investigated. Similarly, the experimenter tried to distract the infant from looking at the wells by calling to the infant during the delay. It was extremely uncommon for an infant to fail to look up in response to this verbal enticement, but infants did not always look up throughout the entire delay. Therefore, the role of visual fixation on performance was also investigated. The results of these analyses were that straining (or turning) toward, or staring at, the correct well during part, or even most, of a delay did *not* increase the likelihood of a correct reach. However, when the infant's strain or gaze was uninterrupted and maintained throughout the delay, success rate was significantly higher than on comparable trials where strain or gaze was not thus maintained (Diamond, 1983). This is consistent with other reports that infants who maintained visual fixation on the correct well reached correctly, while those who shifted their gaze between the wells performed at chance levels (Cornell, 1979; Gratch & Landers, 1971). In the present study, uninterrupted straining or staring occurred so rarely that they do not account for any of the effects to be reported below.

Incremental Changes in Delay

Test 1.—The performance of 18 of the 25 infants (72%) changed in the predicted direction following the change in delay (p = .02, cumulative binomial distribution; see National Bureau of Standards, 1950). The delay was decreased by 2–3 sec for 13 infants who were making the A$\bar{B}$ error during the first half of the session. The performance of nine of these infants (69%) changed to accurate reaching during the second half-session. Four infants continued to make the A$\bar{B}$ error despite the change in delay. The delay was increased by 2–3 sec for 12 infants who were showing accurate performance during the first half of the session. The performance of nine of these infants (75%) changed to the A$\bar{B}$ error during the second half-session. Three infants continued to reach correctly during the second half-session. There was no effect of order of delay presentation as both an increase and a decrease in delay produced the predicted results.

As Table 2 demonstrates, there was no age effect, nor was there an effect of absolute length of delay. For example, it appears that a change of 2–3 sec from a delay of 10 sec was as effective as the same change from a delay of 3 sec. Nor was there a sex effect. The performance of eight of the 11 boys (73%) changed in the predicted direction following the change in delay, as did the performance of 10 of the 14 girls (71%).

TABLE 2

A$\bar{B}$ ERROR DELAY VERSUS SHORTER DELAY: EFFECT OF AN INCREMENTAL CHANGE IN DELAY BY AGE AND ABSOLUTE DELAY LENGTH

Age (in Weeks)	% of Infants Whose Performance Changed Following 2–3-Sec Delay Change	Delay during First Half of Session	% of Infants Whose Performance Changed Following 2–3-Sec Delay Change
≤36	80 (5)	0	80 (5)
37–40	60 (5)	3	60(10)
41–44	80 (5)	5	100 (4)
45–48	80 (5)	7	100 (2)
49–52	60 (5)	10	67 (3)
Total	72(25)	12	0 (1)
		Total	72(25)

NOTE.—Numbers in parentheses indicate the number of infants on which the percentage was calculated. Within order of delay presentation, change in performance was always in one direction only. No infant who was making the A$\bar{B}$ error during the first half of the session ever changed to deteriorated performance when the delay was reduced. If a change occurred, it was to accurate performance. No infant who was reaching accurately during the first half-session ever changed to deteriorated performance when the delay was incremented 2–3 sec. If a change occurred, it was to the A$\bar{B}$ error.

Test 2.—Here order of delay presentation was counterbalanced within subject, so that each of the 10 infants selected for Test 2 received two test sessions. Performance on 16 of these 20 sessions (80%) changed in the predicted direction following the change in delay ($p < .005$, cumulative binomial distribution). On one session per child, the A$\bar{B}$ error occurred on the first half-session, and the delay was decreased by 2–3 sec for the second half of the session. On nine of these 10 sessions, performance changed to accurate reaching; on one session performance did not change. Similarly, on one session per child, following accurate performance during the first half-session, the delay was increased by 2–3 sec for the second half-session. On seven of these 10 sessions, performance changed to the A$\bar{B}$ error following the change in delay; on three sessions performance did not change. On the first testing, performance on 70% of the sessions changed in the predicted direction; on the second testing, performance on 90% of the sessions changed in the predicted direction. Repeated-measures analysis of variance revealed that there was no effect of order of delay presentation, no effect of first or second testing, and no interaction between order and testing. Again, there were no effects of age or of absolute length of delay.

Test 3.—The performance of 10 of the 15 infants (67%) changed in the predicted direction following the change in delay ($p = .15$, cumulative binomial distribution). Delay was increased by 2–3 sec for eight infants making the A$\bar{B}$ error during the first half of the session. The performance of six of these infants (75%) seriously deteriorated following the change in delay. The performance of two infants did not change. Delay was decreased by 2–3 sec for seven infants showing deteriorated performance during the first half-session. The performance of four of these infants changed to the A$\bar{B}$ error during the second half-session. Three infants, however, continued to show deteriorated performance following the change in delay.

The effect of order of delay presentation was not statistically significant, but fewer infants behaved as predicted when the longer delay was presented first. Some infants became so frustrated or distressed during trials at the longer delay that even when the delay was reduced, their performance remained impaired. It is likely that if all 15 infants had received the shorter delay first, a statistically significant effect would have emerged. The performance of roughly two-thirds of the infants changed in Tests 1 and 3. This effect reaches significance for Test 1 but not for Test 3 because of the difference in number of infants tested. The results for Test 3 do not differ by age of infant or by absolute length of delay (see Table 3).

Performance meeting the criteria for the A$\bar{B}$ error differed markedly from performance characterized as accurate or deteriorated. The mean percents of correct reaches at the three performance levels were: A$\bar{B}$ error 63%, accurate performance 97%, and deteriorated performance 21%. The following pattern of behavior was found during A$\bar{B}$ error performance: Infants were correct significantly

TABLE 3

A$\bar{B}$ ERROR DELAY VERSUS LONGER DELAY: EFFECT OF AN INCREMENTAL CHANGE IN DELAY BY AGE AND ABSOLUTE DELAY LENGTH

Age (in Weeks)	% of Infants Whose Performance Changed Following 2–3-Sec Delay Change	Delay during First Half of Session	% of Infants Whose Performance Changed Following 2–3-Sec Delay Change
≤38	80 (5)	0	67 (3)
39–43	60 (5)	3	80 (5)
44–48	60 (5)	5	50 (2)
Total	67(15)	7	67 (3)
		10	50 (2)
		Total	67(15)

NOTE.—Numbers in parentheses indicate the number of infants on which the percentage was calculated. Within order of delay presentation, change in performance was always in one direction only. No infant who was making the A$\bar{B}$ error during the first half of the session ever changed to accurate performance when the delay was increased. If a change occurred, it was to deteriorated performance. No infant whose performance could be characterized as deteriorated during the first half-session ever changed all the way to accurate reaching with a decrease in delay of 2–3 sec. If a change occurred, it was to the A$\bar{B}$ error.

more often than chance on *repeat trials, following correct reaches* ($t = 13.78, p < .0001$), but they were correct significantly less often than chance on *reversal trials, following correct reaches* ($t = 5.20, p < .0001$), and on *repeat trials, following errors* ($t = 5.65, p < .0001$). Performance on *repeat trials, following correct reaches* was significantly better than on any other type of trial (REPEAT, CORRECT vs. REVERSAL: $t = 12.59, p < .0001$, matched-pairs comparison; REPEAT, CORRECT vs. REPEAT, ERROR: $t = 14.20, p < .0001$, matched-pairs comparison) (see Fig. 1). No infant performed as well on *reversal trials, following correct reaches* or on *repeat trials, following errors* as that same infant performed on *repeat trials, following correct reaches*. This pattern of reaching has also been demonstrated by Heth and Cornell (1983) using Markovian analysis to model the performance of infants tested on A$\bar{B}$ in their laboratory.

Accurate performance was characterized by the near absence of errors. There was no significant difference in performance by type of trial. In deteriorated performance, too, there was no significant difference in performance by type of trial. Infants tended to err across all trials. Only in the A$\bar{B}$ error did error rate vary by type of trial.

The behavior of infants who showed deteriorated performance with longer delays differed from behavior normally observed during A$\bar{B}$ testing in other respects as well. Errors of omission (no reach), rare during A$\bar{B}$ testing, marked sessions of deteriorated performance. Sometimes infants looked up with blank expressions on their faces; still more often their failure to reach was accompanied by crying or fretting. Pronounced perseveration and unusually long error strings were also seen. These often had the character of what Piaget has termed "automatisms" (1954, p. 51) and seemed to reflect that the infant had stopped trying.

The results from Test 3 on the detrimental effects of an increase in delay, in combination with the robust findings from Tests 1 and 2 that a reduction of 2–3 sec eliminates the A$\bar{B}$ error, imply that a rather narrow range of delay will produce the A$\bar{B}$ error. A delay just a few seconds too brief produces accurate performance; a delay just a few seconds too long produces deteriorated performance. On those visits where the A$\bar{B}$ error occurred, the delay chosen must have been appropriate to that child, at least within the bounds specified by this range. Differences in the length of delay found for the A$\bar{B}$ error over the course of longitudinal testing thus reflect genuine differences between the children themselves.

Age Differences

The delay at which the A$\bar{B}$ error occurred at each age is summarized in Figure 2. (Age in months was calculated by estimating that there are 4.33 weeks per month.) Linear regression revealed that the age differences in delay needed for the A$\bar{B}$ error are significant ($t = 13.85$ for the coefficient of age, $p < .0001$). There appears to be no evidence of a sudden discontinuity in the length of delay needed for the A$\bar{B}$ error. Rather, the duration of delay necessary for the error increases gradually and continuously at the rate of approximately 2 sec per month.

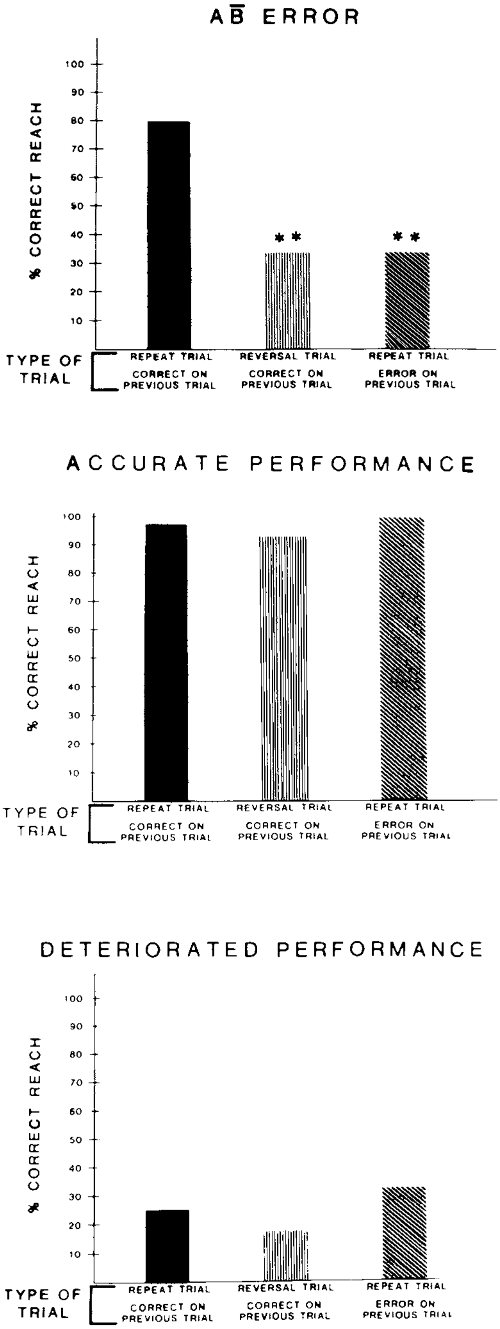

FIG. 1.—Performance level by type of trial for the A$\bar{B}$ error, accurate performance, and deteriorated performance. A delay 2–3 sec shorter than the delay at which the A$\bar{B}$ occurs produces accurate performance. A delay 2–3 sec longer than the delay at which the A$\bar{B}$ error occurs produces deteriorated performance. ** indicates that difference between performance on this type of trial and performance on *repeat trials, correct on previous trial* is significant at $p < .0001$. Note that only during the A$\bar{B}$ error is there a significant difference in performance by trial type.

On the one hand, age accounts for more of the variance in the delay at which the A$\bar{B}$ error occurs than any other variable. On the other hand, age accounts for only about half of this variance ($R^2 = .46$). Individual differences between children of the same age are large, as can be seen by the size of the error bars in Figure 2.

The delays used on all visits for all children followed longitudinally are presented in Table 4. The A$\bar{B}$ error occurred on most of these visits. All infants displayed the A$\bar{B}$ error, and did so repeatedly throughout the months of testing.

A delay that produced the A$\bar{B}$ error in a particular child did not continue to do so for long. For example, at 9 months, no child was making the A$\bar{B}$ error at the same delay that had produced that error in that child at 8 months. At 10 months, only four of the 25 infants studied were still making the A$\bar{B}$ error at the same delay that had produced the A$\bar{B}$ error in the same infants at 9 months.

Sex Differences

Longer delays were needed to elicit the A$\bar{B}$ error in girls than in boys. This can be seen in Figure 3. Regression analysis revealed that the sex difference is significant at $p < .0001$. Girls were able to uncover a hidden object, and hence begin A$\bar{B}$ testing, at a younger age than boys. At 7½ months, 86% of the girls were making the A$\bar{B}$ error, while 45% of the boys could not yet find a hidden object. By 8 months, all the girls were showing the A$\bar{B}$ error, while 36% of the boys had yet to uncover a hidden object. The average delay used with boys of 11 months (8 sec) was equal to the average delay needed by girls at

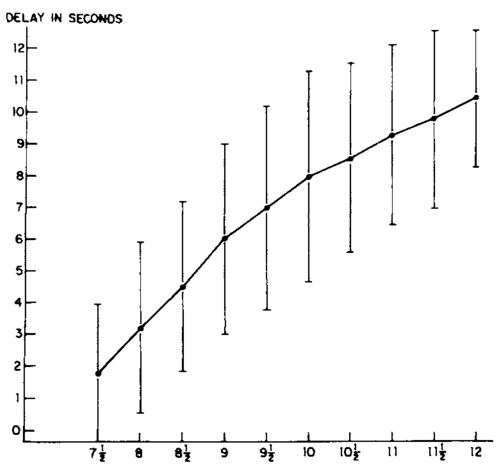

FIG. 2.—Delay at which the A$\bar{B}$ error occurs by age.

TABLE 4

DELAY AT WHICH THE A$\bar{B}$ ERROR OCCURRED ON INDIVIDUAL VISITS FOR EACH CHILD

	AGE (in Months)													% OF VISITS ON WHICH THE A$\bar{B}$ ERROR OCCURRED	TOTAL NO. OF VISITS ON WHICH A$\bar{B}$ WAS TESTED
	6	6½	7	7½	8	8½	9	9½	10	10½	11	11½	12		
Jack	...	...	...	...	...	0	3	5	7	10	10	$\underline{7}$	10	88	8
Lyndsey	...	...	...	1	6	8	8	8	12	(12)	10	10	12	90	10
Tyler	...	...	...	...	...	0	1	4	5	5	5	5	7	100	8
Jamie	...	...	...	0	$\underline{0}$	5	7	7	$\underline{7}$	...	10	15	12	78	9
Emily	...	...	...	0	0	4	4	4	5	7	10	...	...	100	8
Rachel	...	...	1	2	$\underline{2}$	4	8	10	10	10	10	...	10	90	10
Brian	...	0	$\underline{1}$	5	5	5	8	10	10	$\underline{10}$	12	12	12	84	12
Ryan	...	...	...	0	2	3	5	5	3	5	5	7	10	100	10
James	...	...	0	2	5	5	3	5	5	7	8	8	10	100	11
Erin	...	...	1	6	8	10	10	12	12	12	10	$\underline{8}$	10	91	11
Sarah	...	...	...	...	0	$\underline{7}$	8	$\underline{10}$	10	10	10	10	...	88	8
Julia	...	...	...	0	2	5	5	5	7	10	12	12	12	100	10
Mariama	...	...	...	...	3	4	$\underline{2}$	3	5	7	10	12	12	89	9
Kate	...	...	...	0	8	3	10	10	12	12	10	10	10	100	10
Rusty	...	...	...	0	0	(3)	7	10	10	10	10	10	10	90	10
Todd	...	...	...	...	0	5	7	5	5	5	7	8	...	100	8
Nina	...	0	2	3	3	10	10	10	10	10	12	12	12	100	12
Isabel	...	...	1	1	3	7	8	(10)	10	10	10	10	...	90	10
Jennine	...	...	...	0	2	2	(3)	3	5	7	12	12	12	90	10
Jane	...	...	...	$\underline{5}$	7	8	10	(12)	12	12	12	$\underline{9}$	12	70	10
Bobby	...	...	...	0	0	4	4	5	10	10	10	10	8	100	10
Graham	...	...	...	2	2	2	$\underline{4}$	10	12	15	$\underline{12}$	15	15	80	10
Blair	...	...	...	...	...	0	0	0	0	1	2	3	5	100	8
Michael	...	...	...	...	...	$\underline{2}$	5	5	5	7	5	7	10	88	8
Chrissy	...	...	...	2	5	5	10	10	10	10	7	8	...	100	9
Mean	...	...	...	1.7	3.2	4.5	6.1	7.0	8.0	8.9	9.3	9.8	10.6	92.3	9.6

NOTE.—Underscored numbers indicate accurate performance—performance "too good" to be called the A$\bar{B}$ error; numbers in parentheses indicate deteriorated performance—performance "too poor" to be called the A$\bar{B}$ error.

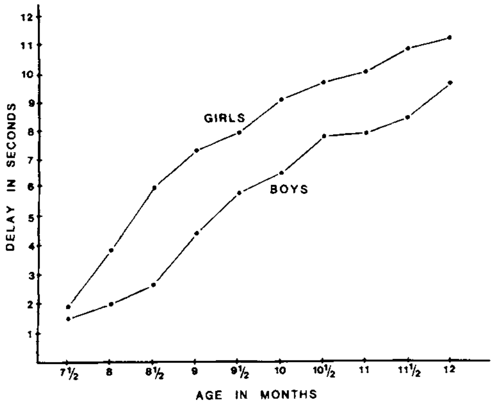

FIG. 3.—Sex differences in the delay needed for the AB̄ error by age.

9½ months, and by 12 months the boys were at the average length of delay that the girls had reached by 10½ months (9.77 sec). Thus it appears that between the ages of 6 and 12 months, girls were maturing faster than boys in regard to the length of delay that could be tolerated in the AB̄ situation.

Although age is the single best predictor of the length of delay an infant can tolerate, knowing both the sex and age of an infant significantly improves one's ability to predict the delay that will produce the AB̄ error in that child. Regression models that include sex and age as independent variables account for the data significantly better than does the regression model that has age alone as the independent variable ($p < .0001$).

The only sex difference was in the delay necessary to produce the AB̄ error. An increase or decrease in delay affected boys and girls similarly. The pattern of reaching characterizing the AB̄ error was the same regardless of sex (percentage of correct reaches on repeat trials following correct reaches: girls 79%, boys 79%; percent correct on reversal trials following correct reaches: girls 33%, boys 36%; percent correct on repeat trials following errors: girls 29%, boys 40%).

Discussion

Universality, Individual Differences, and Stability of the AB̄ Error

The AB̄ error occurred in all children and persisted for several months. This disagrees with other published reports. Investigators studying cross-sectional samples of children (e.g., Butterworth, 1975) have reported the AB̄ error in only about half of their subjects. Investigators studying AB̄ longitudinally, but using the same delay at all ages, have found the error to disappear within a month or two (e.g., Gratch & Landers, 1971).

There are probably three reasons for these discrepancies. One, large between-subject differences exist in the delay producing the AB̄ error in same-aged children (see Table 4). If one uses a standard delay for all children, it is likely to be too short for many children, and so long for others that their performance deteriorates below AB̄ error criteria. For example, girls require longer delays than do boys for the AB̄ error. Throughout the months of AB̄ testing, girls were able to tolerate delays about 2½ sec longer than could boys of the same age. Investigators who found the AB̄ error in only about half their subjects used the same length of delay for all infants.

Two, using performance on a single reversal trial as the criterion for the AB̄ error yields different results from those reported here. Many investigators have used a single trial (the first "B" or reversal trial) to determine the presence or absence of the AB̄ error. With that criterion, the AB̄ error occurred only about half the time even in the present study. (Across all sessions, the percentage of correct reaches on the first reversal trial within a session was 42%; percent correct for the second reversal was 50%; for the third reversal it was 51%; Diamond, 1983.) However, by using a criterion that examines performance over several trials, and by tailoring delay to the child, the AB̄ error was found in all children in the present study.

Three, the period of efficacy of any single delay is brief for each child. Investigators who report that the AB̄ error disappeared after a month or so continued to use a single delay throughout testing. In the present study, a large range of delays (0–15 sec) was used, and from the age at which the AB̄ error first appeared until at least 12 months (when testing stopped), infants continued to make the error, as long as delay was incremented with age.

Sensitivity to Delay

The range of delay that will produce the AB̄ error pattern in a particular infant of 6–12 months is small. Infants who are making the AB̄ error at a given delay cease to err ("accurate performance") if the delay is reduced by 2–3-sec. They reach randomly, or show signs of distress ("deteriorated performance"), if the delay is increased by 2–3 sec. At these longer delays, infants no longer reach correctly even on *repeat trials, following correct reaches.* Once performance is deteriorated, reducing the delay does not always lead to improved performance. So difficult is the task at longer delays that infants "give up" or become so frustrated that their performance does not improve even when easier trials, at shorter delays, are presented later.

It should be emphasized that the reference point for all tests was the delay at which the A$\bar{B}$ error occurs. A reduction of 2–3 sec will eliminate the A$\bar{B}$ error. However, if one finds a delay at which an infant reaches correctly, a 2–3-sec increment will not necessarily result in the A$\bar{B}$ error. For example, an infant who commits the A$\bar{B}$ error at a delay of 12 sec will succeed at 3 sec and also at 6 and 9 sec. Some testing sessions in the present study could begin at the briefer delay only because the same infants were tested every 2 weeks, and so a good estimate could be made of the delay for the A$\bar{B}$ error.

The A$\bar{B}$ error indicates that the upper reaches of the child's ability on this task have just been exceeded. This is more precise information than can be inferred from either errorless or random performance, where the task may have been much too easy or much too difficult for the child. When the A$\bar{B}$ error appears, we know we are at the border.

Delay Needed for the A$\bar{B}$ Error by Age

The delay needed to produce the A$\bar{B}$ error increased continuously at an average rate of about 2 sec per month, from under 2 sec at 7½ months to over 10 sec by 12 months. These results accord well with other published results. The major longitudinal studies of A$\bar{B}$ have come out of the laboratories of Gratch (Gratch & Landers, 1971) and Kagan (Fox et al., 1979). Gratch and Landers found that 8-month-olds made the A$\bar{B}$ error at 3 sec, as did the present study. Gratch and Landers found the average age of onset of the A$\bar{B}$ error (3-sec delay) to be 8 months (range = 6½–9 months). This compares well to the present finding that the average age of onset of the A$\bar{B}$ error (0-sec delay) was 7½ months (range = 6½–8½ months).

Fox et al. (1979) also found that infants of 8 months made the A$\bar{B}$ error at a delay of 3 sec. Gratch and Landers neither distracted nor restrained their infants. Fox et al. restrained the infants, but did not attempt to break their visual fixation (opaque screen was used with a cross-sectional sample only). In the present study, infants were distracted and restrained. Yet in all three investigations it was found that a 3-sec delay produced the A$\bar{B}$ error in 8-month-old infants. For infants of 9 months, Fox et al. report no errors at 3 sec, and the A$\bar{B}$ error at 7 sec (no distractor, infant physically restrained). This, too, compares well to the present finding that 9-month-olds made the A$\bar{B}$ error at 6 sec (verbal distractor, restrained).

In cross-sectional studies, the A$\bar{B}$ error has generally been found at delays a few seconds shorter at each age than is found in longitudinal studies. For example, in a cross-sectional study, Harris (1973) found that 10-month-old infants made the A$\bar{B}$ error at 5 sec. By 10 months, in the present longitudinal sample, the A$\bar{B}$ error was found at 8 sec, and Fox et al. report that delays greater than 7 sec were needed. In our laboratory, too, infants tested on A$\bar{B}$ only once between the ages of 7 and 12 months made the A$\bar{B}$ error at delays a few seconds briefer at each age than did infants with previous testing on A$\bar{B}$ (Diamond, 1983). There are several possible explanations for this. One is practice effects; repeated testing on A$\bar{B}$ may improve performance or hasten the rate of improvement. Another explanation might be that the task, experimenter, and testing room are unfamiliar to a child on the first testing, and performance therefore may suffer.

Using other paradigms, results on delay by age congruent with those reported here have also been obtained. Brody (1981) trained infants on a two-location, indirect delayed response task. A light appeared at one of the locations, a delay was imposed (during which an opaque screen was lowered), and then the infant was allowed to reach. Infants were rewarded for reaching to where the light had been. She found that 8-month-olds succeeded with a 0-sec delay, but reached incorrectly with delays of 3 sec or more. Three seconds is the delay at which the A$\bar{B}$ error appears at 8 months. At 12 months, Brody found that infants succeeded with delays of 0, 3, 6, and 9 sec. By 12 months, delays of 10½ sec are required before the A$\bar{B}$ error appears.

Millar and Watson (1979) studied the effect of delayed reinforcement on the acquisition of a conditioned response in infants 6–8 months old. They found that the response was acquired when the delay between response and reinforcement was 0 sec, but not when the delay was 3 sec or more. They speculate that the duration of short-term recall for a stimulus-response contingency is 3–5 sec for infants under 9 months. These results are consistent with those presented here.

Using habituation and operant-learning paradigms, however, retention in infants the same age or even several months younger than those studied here has been demonstrated over periods of days and weeks (e.g., Cohen & Gelber, 1975; Cohen, Gelber, & Lazar, 1971; Fagan, 1973, 1977; Lipsitt, Kaye, & Bosack, 1966; Olson, 1976; Rovee & Fagen, 1976; Rovee-Collier, 1981; Rovee-Collier & Fagen, 1981; Sullivan, Rovee-Collier, & Tynes, 1979). Such delay intervals are far greater than the delays of 0–15 sec reported here. Clearly, the A$\bar{B}$ paradigm requires a different ability from the one needed to acquire such conditioned responses.

Success at an operant task usually depends on learning and remembering a single association between a stimulus and response. For example, if reaching to the left well were always rewarded, relying on this one fact would produce a correct reach on every trial. On A$\bar{B}$, however, no visible stimulus and no single rule (such as "reach left") can successfully guide the infant's reach. The infant must keep track of the toy on each trial and hold this in short-term memory. Indeed, when a landmark indicates the toy's location on each trial, infants do not err on A$\bar{B}$ even at long delays (Diamond, 1983). The landmark condition requires memory, just as do all operant paradigms, for the infant must remember the association between landmark and toy. However, once this association is learned, the infant can use the landmark to guide reaching on all trials. On A$\bar{B}$ without a landmark, the infant must pay attention to the hiding on each trial and continually update the mental record of the toy's location.

Pattern Characterizing the A$\bar{B}$ Error

The A$\bar{B}$ error consists of a particular pattern of reaching: errors are confined to specific trials (i.e., *reversal trials* and *repeat trials, following errors*); infants are correct on *repeat trials, following correct reaches.* This differential performance across trials occurs despite a constant delay across trials.

On the one hand, short-term recall memory appears to be one of the abilities required for the A$\bar{B}$ task. Varying delay between hiding and retrieval, holding everything else constant, significantly affects whether or not the A$\bar{B}$ error appears. For example, Fox et al. (1979) found that 9-month-old infants made the A$\bar{B}$ error at a 7-sec delay but reached correctly at a 3-sec delay. In the present study it was found that, regardless of age, reducing the delay at which the A$\bar{B}$ error occurs by 2–3 sec produces correct reaching, and increasing the delay by 2–3 sec produces deteriorated reaching. Errors are rare when memory is not required for the task, as when (*a*) the infant stares at the correct well until allowed to reach, (*b*) the infant maintains a bodily orientation toward the correct well until allowed to reach, (*c*) no delay is imposed, or (*d*) the toy remains visible in the well.

On the other hand, it is clear that memory cannot fully explain the A$\bar{B}$ error. Some errors occur when memory is not required, as studies using transparent covers have shown. Also, performance varies by type of trial, although delay does not. Since the memory requirements of all trials considered as isolated units are the same, a factor other than memory must be responsible for the pattern of performance across trials.

A proactive interference interpretation, such as suggested by Harris (1973), can account for impaired performance on reversal trials, but has difficulty accounting for errors when memory is not required. An alternative interpretation is that A$\bar{B}$ sets up a competition between the ability to use short-term recall to guide behavior and a conditioned behavioral tendency to repeat a rewarded response. Success at A strengthens the tendency to reach to A. The factor, then, in addition to memory, required for success on A$\bar{B}$, is the ability to resist the conditioned tendency to reach back to A.

The pattern of performance across trials that characterizes the A$\bar{B}$ error appears to follow the laws of learning theory. Infants err on reversals after only one or two successful trials at the earlier hiding place (consistent with the appearance of conditioned habits after only one or two trials). Infants err again over the next several trials at the new hiding place (consistent with more trials required to extinguish, than to establish, a conditioned habit). When the A$\bar{B}$ error occurs, the conditioned habit to return to the location where the infant was previously rewarded (A) appears to override the "intention" to reach to B, based on the memory of where the toy was just hidden.

Whereas a proactive interference interpretation posits that memory is disrupted or interfered with, ***the present interpretation posits that errors can occur in the face of accurate recall.*** Infants who "know" where the toy is because they can see it, or because they accurately remember where it has been hidden, may nevertheless reach incorrectly because of a failure to resist the "habit" to repeat the old, successful response.

According to this interpretation, errors should always follow the same pattern, even with transparent covers. And the same pattern is indeed found. Errors occur significantly more often on *reversal trials, following correct reaches* than on *repeat trials* *following correct reaches*, even when transparent covers are used (Butterworth, 1977).

Indeed, evidence exists that babies may remember, at some level, where the toy has been hidden, but when the delay becomes too long, the influence of memory over their behavior is not strong enough to hold back their habitual response. The first piece of evidence is that, given a chance to correct themselves after reaching incorrectly, infants usually do so straightaway (Diamond, 1983; Harris, personal communication; Webb, Massan, & Nadolny, 1972). Second, infants often uncover the wrong well, do *not* look in to see if the toy is there, reach immediately to the correct well, and retrieve the toy. The fact that they do not look for the toy at their initial choice suggests that they may "know" their initial reach is wrong. Third, infants occasionally look squarely at the correct well as their hand reaches back to uncover the well where the toy used to be. If looking, rather than reaching, were the dependent measure, infants would be scored as correct on such trials. Here, the infants appear to be telling us with their eyes that they know where the toy is, but their hand goes to the old place anyway.

There may be an adult analogue of this; it is seen in people with damage to the frontal lobe of the brain. They often "know" the correct answer, and can tell it to you, but cannot alter their behavior to express it. When information counter to a conditioned tendency is made available to frontal lobe patients, they often cannot use it to override the acquired tendency. For example, such patients can deduce the correct criterion for sorting a deck of cards. But when the experimenter changes the criterion, frontal patients cannot switch to sorting the cards by this new rule. Importantly, however, patients often say as they continue to sort the cards incorrectly, "Shape is probably the correct solution now, so this sorting by color will be wrong and this will be wrong, and wrong again" (Luria & Homskaya, 1964; Milner, 1964; Nauta, 1971). Goldman-Rakic and I have recently demonstrated that the frontal lobe is required for successful A$\bar{B}$ performance in the rhesus monkey (Diamond & Goldman-Rakic, 1983).

The present interpretation of A$\bar{B}$ also leads to the prediction that, if multiple wells are used, errors will always be in the direction of the previously correct well when the delay for the A$\bar{B}$ error is used. When recall of the hiding at B is not firm and clear, the pull to reach to A should deflect the infant's reach, almost like a magnet. The deflection need not be large, but it should always be toward A in situations that allow an infant to choose among wells on either side of B. A memory interpretation, on the other hand, would predict that infants would distribute their reaches randomly across the wells. Specifically, infants would reach equally to wells on either side of the B location.

Cummings and Bjork (1981, 1983) have used multiple-well testing arrangements. In one of their conditions, the wells were arranged so that infants could indeed reach toward A or away from A as defined above, the test required of the two competing predictions just stated. Six wells were used; A was located at position 2 and B was at position 5. This provided an opportunity for infants to reach away from A (i.e., to position 6). No infant did so on the reversal trial; 65% of the infants erred, and all errors were in the direction of A (Cummings & Bjork, 1983). This finding agrees with the present prediction, but it requires replication. Only one reversal was given, and the wells were arranged in a straight line that produces a bias to reach to the midline (Butterworth, 1976; Lloyd, Sinha, & Freeman, 1981). Indeed, when Cummings and Bjork placed well B at the middle of their multiple-well arrangement, no infant erred on the reversal trial (with three or five wells).

The prediction offered here does not state whether errors will be closer to B or to A, but only that they will be to the A side of B rather than away from A. Cummings and Bjork found that errors tended to be closer to B than to A. However, this too requires replication, as some of their procedures may have maximized the accuracy of the reaches—for example, their manner of covering the wells (see Harris, 1973, Experiment III), the delay used (in other cross-sectional studies, most infants of the same age have reached correctly at that delay; Butterworth, 1977; Fox et al., 1979), and the failure to prevent staring, leaning, or turning during the delay, although reaching was prevented (Cornell, 1979; Diamond, 1983; Fox et al., 1979; Gratch & Landers, 1971).

In conclusion, longer delays are needed to produce the A$\bar{B}$ error as infants grow older. The pattern of behavior, however, does not change with age. The character of the error remains the same over these months because it is always due to the same underlying cause—the failure of a memory-based intention to override habit. Few errors are made when memory is not taxed, as with a short delay or transparent covers. Few errors are made when it is not necessary to resist a prepotent response, as on repeat trials following correct reaches. Most errors occur when demands are placed on both abilities. Improved performance on A$\bar{B}$ with age, therefore, indicates the development of the ability to use stored information to guide behavior in the face of an acquired tendency to do otherwise. This achievement depends on both recall memory and the ability to resist or inhibit prepotent response tendencies.

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