Martha Ann Bell
Virginia Polytechnic Institute and State University Department of Psychology
Blacksburg, VA 24061–0436

Nathan A. Fox
University of Maryland Institute for Child Study
College Park, MD

Individual Differences in Object Permanence Performance at 8 Months: Locomotor Experience and Brain Electrical Activity

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Abstract: *This work was designed to investigate individual differences in hands-and-knees crawling and frontal brain electrical activity with respect to object permanence performance in 76 eight-month-old infants. Four groups of infants (one prelocomotor and 3 with varying lengths of hands-and-knees crawling experience) were tested on an object permanence scale in a research design similar to that used by Kermoian and Campos (1988). In addition, baseline EEG was recorded and used as an indicator of brain development, as in the Bell and Fox (1992) longitudinal study. Individual differences in frontal and occipital EEG power and in locomotor experience were associated with performance on the object permanence task. Infants successful at A-not-B exhibited greater frontal EEG power and greater occipital EEG power than unsuccessful infants. In contrast to Kermoian and Campos (1988), who noted that long-term crawling experience was associated with higher performance on an object permanence scale, infants in this study with any amount of hands and knees crawling experience performed at a higher level on the object permanence scale than prelocomotor infants. There was no interaction among brain electrical activity, locomotor experience, and object permanence performance. These data highlight the value of electrophysiological research and the need for a brain-behavior model of object permanence performance that incorporates both electrophysiological and behavioral factors.* © *1997 John Wiley & Sons, Inc.* Dev Psychobiol **31:** 287–297, 1997

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In the recent developmental literature there have been two separate lines of research emphasizing individual differences in object search performance among same-age infants. Researchers from these two perspectives have implicated self-produced locomotion (e.g., Bertenthal, Campos, & Kermoian, 1994) and dorsolateral prefrontal cortex (e.g., Diamond, 1990a, 1990b) as contributing either directly or indirectly to these individual differences in search performance. While these two areas of work appear to be fuel for the classic maturation versus experience debate, it may be that

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Correspondence to: M. A. Bell
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their contributions to search performance are not independent of each other.

A growing number of researchers have proposed that the developmental motor milestone of hands and knees locomotion is associated with successful search behavior in object permanence paradigms. Both Bremner (1978) and Acredolo (1990) have suggested that self-locomotion results in a changing perspective of the environment that serves to show the infant that egocentric spatial relations do not aid in relocating objects. Bertenthal et al., (1994) have proposed that locomotion is functionally related to the development of infant cognitive behaviors. The crawling infant may develop an understanding of how objects are interrelated in the environment by using environmental landmarks to constantly update spatial relations that continually are changing as the infant locomotes.

Studies utilizing a 2-hiding site, object-search paradigm have shown that locomotor infants are better than prelocomotor infants at finding hidden objects (Horobin & Acredolo, 1986) and are better at finding hidden objects after self-initiated locomotion toward the hiding site, as opposed to being passively carried to the hiding site (Acredolo, Adams, & Goodwyn, 1984; Benson & Uzgiris, 1985). Locomotor infants are more successful in finding a hidden object, as opposed to prelocomotor infants, after relocation of the infant by the parent (Benson, 1990), and after displacement of the infant, as opposed to displacement of the hiding sites (Bai & Bertenthal, 1992). In a study of locomotor experience utilizing an ordinal object permanence scale that included the A-not-B task with and without a delay period, Kermoian and Campos (1988) reported that infants with 9 or more weeks of hands-and-knees locomotor experience performed at a higher level than either the prelocomotor infants or the locomotor infants with less than 4 weeks crawling experience. Kermoian and Campos speculated that the onset of hands-and-knees locomotion may promote brain maturation and, thus, object permanence performance.

A second factor from the developmental literature that has been implicated in individual differences in performance on object permanence tasks is the rate of maturation of a specific area of the frontal cortex. Diamond has demonstrated, with nonhuman primate data, that successful performance on the A-not-B task depends upon maturation or integrity of the dorsolateral prefrontal cortex (Diamond, 1990a, 1990b). Infant monkeys follow the same developmental progression on A-not-B as do human infants (Diamond & Goldman-Rakic, 1989). Infant monkeys receiving lesions in both hemispheres of the dorsolateral prefrontal cortex were unable to succeed on A-not-B with a delay between hiding and search (Diamond & Goldman-Rakic, 1986). Adult monkeys with prefrontal lesions also were hampered, compared to normal or hippocampal lesioned monkeys (Diamond, Zola-Morgan, & Squire, 1989).

Diamond has proposed that associated with the maturation of the dorsolateral prefrontal cortex is the ability to hold a representation of the hidden object in a specific location (i.e., memory) and the ability to inhibit a prepotent motor response (1990a, 1990b; Diamond, Cruttenden, & Neiderman, 1994). These are the skills that the infant must master in order to succeed on the A-not-B task. Both Fuster (1980) and Pribram (1973) also have proposed that the prefrontal cortex has interactive functions: a temporally retrospective function of working memory, a temporally prospective function of anticipatory set, and an interference-control mechanism that suppresses behavior incompatible with the goal. In a recent article on the ontogeny of memory, Nelson (1995) noted that dorsolateral prefrontal cortex is probably involved in success on the A-not-B task. He also suggested that other cortical and subcortical structures may work in coordination with dorsolateral prefrontal cortex to enable successful performance.

Building upon Diamond's notions, Bell and Fox (1992) reported EEG differences between a group of infants in a longitudinal study who tolerated increasing delay in the A-not-B task from 7 to 12 months of age and a group of infants unable to tolerate increasing delay across the same age span. Although not replicating Diamond's (1985) report of the amount of delay tolerated by infants at 12 months of age[1], Bell and Fox did find that infants tolerating the increasing delay displayed changes in power at the frontal electrode sites across age. Infants unable to tolerate increasing delay showed no changes in frontal EEG power across the same age span. Bell and Fox concluded that differences in maturation of certain areas of the frontal region, as indexed with EEG, are related to variation in object permanence performance during the last half of the 1st year of life.

Recently Diamond (1991) posited that the specific type of memory essential for successful performance of the A-not-B object permanence task is memory for a sequence of actions. Object permanence tasks require the infant to combine remembered actions per-

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[1] The norms published by Diamond (1985) have not been replicated. Diamond reported on a developmental progression on A-not-B performance and noted that a 10-s delay was tolerable by 12-month-old infants in her longitudinal sample. Bell and Fox (1992) reported a 7.5-s delay for their longitudinal sample (7 to 12 months of age) and Matthews, Ellis, and Nelson (1996) reported a 5-s delay (28 to 60 weeks of age). However, Bell and Fox, as well as Matthews et al., do report that infants showed a developmental progression in the amount of delay tolerated on A-not-B.

formed by the experimenter into a behavioral sequence that the infant must reenact in order to retrieve the hidden object. While the motor cortex and posterior parietal cortex generate and control reaching in space (Ghez, 1985), the premeditation of a voluntary sequence of actions is linked to the supplementary motor area of the frontal cortex (Georgopoulos, 1995; Kupfermann, 1985). Thus, the frontal cortex may be involved in the *planning* of motor movements essential for object permanence performance. Likewise, the frontal cortex may be involved in the planning of motor movements exhibited during crawling. The actual crawling sequence itself is not under cortical control, however, but is located at the spinal cord level (J. E. Clark, personal communication, May 23, 1991). If the supplementary motor area of the frontal cortex is involved with the planning of the crawling sequence, then there may be some relation between hands-and-knees locomotion and object permanence performance.

The purpose of this research was to attempt to merge the separate literatures on individual differences in object permanence performance by examining both hands-and-knees locomotor experience and maturation of the frontal cortex (measured via EEG), in a group of same-age infants. These hypotheses were made: (a) Infants with longer locomotor experience would performance at higher levels on an object permanence task as compared to prelocomotor and novice locomotor infants, in a replication of the work by Kermoian and Campos (1988). (b) There would be EEG differences between infants who performed at a higher level on the object permanence task and those performing at a lower level. In a same-age study replication of Bell and Fox's (1992) longitudinal work, it was proposed that these differences would be specific to the frontal scalp leads. (c) There would be an interaction among locomotor experience, EEG power values, and object permanence performance such that infants with longer locomotor experience and greater frontal EEG power would be performing at higher levels on the object permanence task than other infants.

METHODS

Participants

Eighty healthy, full-term, 8-month-old infants (90% caucasian, 6% black, 3% Hispanic, 1% Asian) were participants for this study. Infants were born to middle- and upper-middle-class parents (Each parent had a minimum educational level of high school diploma.) and were recruited via local newspaper advertisements and new-parent mailing lists. All infants were born within 2 weeks of their calculated due dates, weighed at least 6 pounds at birth, and required no oxygen after delivery. In addition, none of the infants were diagnosed as having neurological problems and none had ever sustained a head injury. All infants in the study were born to parents who both indicated right-handedness on a general information survey. Infants were seen in the laboratory within 2 weeks of their 8-month "birthday."

Based on telephone interviews with the mothers during recruitment, infants were grouped according to locomotor experience in the same manner as that done by Kermoian and Campos (1988). There were four locomotor groups: infants with 1–4 weeks of hands-and-knees crawling experience ($n = 20$, half female), infants with 5–8 weeks of crawling experience ($n = 20$, half female), and infants with 9 or more weeks of crawling experience ($n = 20$, half female). During recruitment each mother was asked if her infant had begun to crawl on hands and knees with belly off the floor and, for each mother who answered in the affirmative, how many weeks her infant had been doing this particular type of crawling. After the mother stated a specific number of weeks, the recruiter verified the length of time crawling by calculating the infant's age at crawling onset ("So he started crawling at 6½ months of age?") and by referencing the length of time reported by the mother to a common social event ("So she was crawling on the Fourth of July?"). This verification process, similar to that reported by Kermoian and Campos (1992), allowed each mother to confirm the length of time and/or the age at which her infant had begun hands-and-knees crawling. In this study there was also a group of prelocomotor or "precrawling" hands ($n = 20$, half female). Excluded from the study were infants who crawled with their bellies touching the floor and infants who had locomotor experience in an infant walker prior to crawling on their hands and knees.

Procedures

Electrophysiological Recording. Brain electrical activity (EEG) was recorded from eight sites: left and right medial frontal, lateral frontal, parietal, and occipital regions (F3, F4, F7, F8, P3, P4, O1 and O2) referenced to Cz. The EEG was recorded for 3 min while the infant sat on mother's lap. During the EEG recording, a research assistant rotated a bingo wheel filled with brightly colored ping-pong balls 3 ft in front of the infant. This procedure quieted the infant and yielded minimal eye movements and gross motor movements while allowing the infant to tolerate the

EEG cap for the recording. This bingo wheel procedure alternated between 10 s of rotating ping-pong balls and 10 s of no rotation. The "no rotation" EEG was used as the baseline EEG for this study. The mother was instructed not talk to her infant during the EEG recording.

EEG was recorded using a stretch lycra cap (Electro-Cap) which contained electrodes in the 10/20 system pattern (Jasper, 1958). After the cap was placed on the infant's head, a small amount of abrasive was placed into each recording site and the scalp gently abraded. Following this, a small amount of conductive gel was placed in each site. EEG electrode impedances were measured and accepted if they were below 5K ohms. This impedance level is the standard to ensure quality EEG recordings (Pivik et al., 1993). Beckman miniature electrodes were placed on the external canthus and the supra orbit of the right eye and used for artifact editing the EEG based on eye movements.

The electrical activity from each lead was amplified using separate Grass amplifiers (Model 7P11) and bandpassed from 1 to 100 Hz, with a notch filter at 60 Hz. Activity for each lead was displayed on separate channels of a Grass Model 78 polygraph. The EEG signal was digitized on-line at 512 samples per s for each channel so that the data were not affected by aliasing. The raw data were stored for later analysis.

The EEG data were examined and analyzed using software developed by James Long Company. First, the EEG data were re-referenced via software to an average reference configuration. Average referencing, in effect, weighted all the electrode sites equally and eliminated the need for a noncephalic reference. Active (F3, F4, F7, F8, P3, P4, O1, O2) to reference (Cz) electrode distances vary across the scalp. Without the re-referencing, power values at each active site may reflect interelectrode distance as much as they reflect electrical potential. The average reference EEG were scored for eye movement and motor artifact and artifacted data were eliminated from subsequent analyses. The data then were analyzed with a discrete Fourier transform (DFT) using a Hanning window of 1-s width and 50% overlap. Prior to computation of the DFT, the mean voltage was subtracted from each data point to eliminate any power results due to DC offset. Power was computed for the 6- to 9-Hz frequency band. Infants of 8 months of age have a dominant frequency in all EEG leads between 6 to 9 Hz (Bell & Fox, 1994). The power was expressed as mean square microvolts and the data were transformed using the natural log (ln) to normalize the distribution.

One female infant with 1–4 weeks crawling experience exhibited EEG power values that were greater than three standard deviations above the power values of the other infants and her data were eliminated. Due to equipment failure, 3 other infants (2 girls with no locomotor experience and 1 boy with 9+ weeks experience) were missing data for one of the EEG leads. Data for these 3 infants were eliminated and the final participant number was 76.

Object Permanence Scale. Each infant was tested on the following object permanence scale that was constructed to demonstrate a wide range of individual differences in object permanence performance in 8-month-old infants. These items are similar to those employed by Kermoian and Campos (1988).

1. Object partially covered with one cloth.
2. Object completely covered with one cloth.
3. Object hidden under one of two identical cloths.
4. A-not-B with 0 delay.
5. A-not-B with 2-s delay.
6. A-not-B with 4-s delay.
7. A-not-B with 6-s delay.
8. A-not-B with 8-s delay.

The Permanence of Objects Scale of the Ordinal Scales of Psychological Development designed by Uzgiris and Hunt (1975) was used as a guide for object permanence scale Items 1–3 above. During testing, the infant was seated on the mother's lap at a table. The examiner was seated opposite the infant and offered the infant an attractive toy (e.g., brightly colored rattle, small squeaky toy). After the infant manipulated the toy briefly, the examiner removed the toy and administered object permanence scale Items 1–3 using the following procedures:

1. Finding an object which was partially covered: The examiner placed the toy in front of the child and covered it with one cloth in such a way that a small portion of the object remained visible.
2. Finding an object which was completely covered: The examiner placed the toy in front of the child and covered it with one cloth so that it was no longer visible.
3. Finding an object which was completely covered with a single screen in two places: The examiner placed the toy under one of two identical cloths.

The experimenter signaled the beginning of a trial for each of the first three tasks on the object permanence scale by holding up a toy to attract the infant's attention. The experimenter then administered the task. If the infant's attention was lost during the trial, the examiner regained the attention by tapping the toy on the table and calling the infant's name and proceeded with scale administration. Each infant was required to successfully retrieve the toy from the correct cloth in two out of three trials to be declared competent at a specific object permanence scale item.

Upon successful completion of object permanence scale Item 3 above, the A-not-B procedure was begun. Items 4–8 of the object permanence scale used in this study employed an A-not-B task procedure modeled after the standard two-location task commonly used in the developmental psychology literature; i.e., there were identical covers and backgrounds, the same object was used throughout the task, the two hiding locations were horizontally oriented, and the object was hidden at the same location on all *A* trials and then hidden at the other location on the *B* trial (Wellman, Cross, & Bartsch, 1986). For this study, the A-not-B task apparatus was a cardboard box which measured 47.5 cm (L) × 22.5 cm (W) × 7.5 cm (D). It contained two wells 9.5 cm in diameter, 7.5 cm deep, and 29 cm apart from center to center. White fabric cloths used to cover the wells measured 20 cm square.

The A-not-B task apparatus was placed on the table in front of the infant so that the center of the box was at midline and the cloths covering each well were within reach of the infant. The experimenter was seated on the opposite side of the table facing the infant and parent. A large assembly of toys sized to fit in the apparatus wells was accessible to the experimenter. After two successful retrievals at side *A*, the toy was then hidden in the opposite Well *B*. Infants who successfully recovered the toy in two out of three reversal trials (i.e., did not make the A-not-B error) were then tested with 2-s delay. Subsequent delays were initiated until the infant made the A-not-B error two out of three trials at any given delay. Delay was incremented in 2-s intervals throughout the study. Using a procedure similar to that of Diamond (1985) and Bell and Fox (1992), a distractor was employed during the delay to break visual fixation to the correct well. Under delay conditions, the mother was asked to hold the infant's hands while the experimenter snapped her fingers, smiled at the infant, and counted to divert the infant's gaze from the well. After the delay period the infant's hands were released and the infant permitted to search. Citing work by Cornell (1979) and Fox, Kagan, and Weiskopf (1979), Diamond (1985) has argued that a verbal distractor is necessary because visual fixation to the correct well can be used to simplify the A-not-B task. For the present study, each infant was required to successfully retrieve the toy from the *B* well in two out of three *AAB* trials to be declared competent at a given delay.

Object permanence testing was stopped after the infant failed two out of three trials at a particular task on the object permanence scale. Uzgiris and Hunt (1975) have demonstrated the ordinal nature of object permanence Items 1–3 above, and Diamond (1985) has shown that the range of delay producing the A-not-B error in any one infant at a particular testing session is small. Infants were assigned a score equal to the highest level completed on the object permanence scale. For example, an infant whose highest level of performance was success on A-not-B with 0 delay received a score of 4.

All coding of the object permanence scale was done from videotape of the laboratory session by the experimenter. A research assistant coded 25% of the subjects' videotapes (5 subjects from each locomotor group) for reliability purposes. Reliability coding using percent agreement was 90%. The two discrepancies were discussed and an agreement reached as to the object permanence performance level.

Locomotor Assessment. An infant was initially placed in one of the four locomotor groups (prelocomotor, 1–4 weeks, 5–8 weeks, or 9+ weeks crawling experience) based on the telephone interview with the mother during recruitment. At completion of the laboratory testing, the infant's crawling status was assessed. The infant was placed on the floor and encouraged to crawl to mother sitting 6 ft away. For an infant to be placed in one of the three crawling categories, the infant must have been able to make contact with mother by hands-and-knees locomotion. The prelocomotor infant was not able to get to mother. One infant whose mother had labeled him as a "hands-and-knees crawler" during telephone interviews actually belly-crawled to mother after the testing session. This infant's data were discarded and an infant with the appropriate length of hands-and-knees crawling experience was recruited to replace him. Reliability coding of the videotaped crawling resulted in 100% agreement as to whether the infant was a prelocomotor or hands-and-knees crawling participant.

RESULTS

Object Permanence Performance

Figure 1 presents the data for the performance of the infants on the specific items of the object permanence scale. The graph represents each infant's highest level of performance on the object permanence scale and, thus, includes data for all 76 infants. As can be seen, most of the 8-month-old infants in this study could succeed on the A-not-B task at 0 delay. The infants

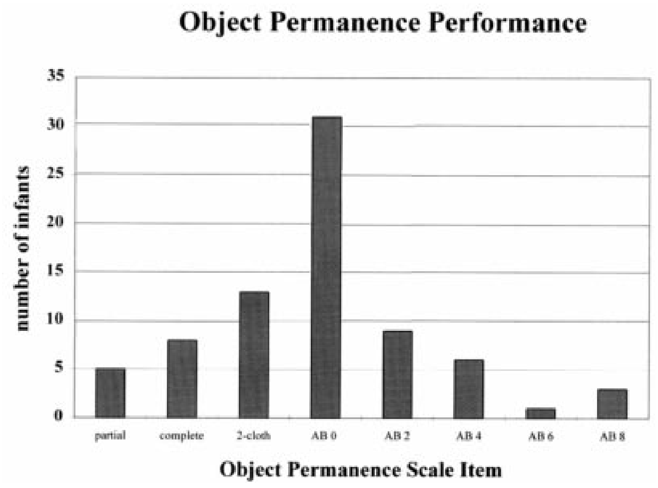

FIGURE 1 Individual infant performance on the object permanence scale. *X* axis represents items on the object permanence scale. *Y* axis represents the number of infants whose best performance was at each scale item.

were divided into three groups based on their score on this scale so that object permanence group membership could be used as a marker of between subjects object permanence performance in some of the subsequent analyses. Infants who performed below A-not-B level (i.e., infants whose highest level of performance was to uncover a partially hidden object, a completely hidden object, or uncover an object from one of two possible hiding sites) were grouped together. These 26 infants were classified as unable to do the A-not-B task. The 31 infants who could succeed on the A-not-B task without any delay were the second performance group. The remaining 19 infants comprised the third performance group: those infants who could succeed on the A-not-B task with delay of 2 or more seconds.

Object Permanence and Locomotor Experience

Results of a one-way ANOVA revealed that the four locomotor groups performed differentially on the object permanence scale, $F(3, 72) = 7.82$, $p \leq .001$. The three groups of crawling infants, 1–4 weeks: $M = 4.53$, $SE = .28$; 5–8 weeks: $M = 3.75$, $SE = .21$; 9+ weeks: $M = 4.60$, $SE = .39$, had means that did not differ from each other, Newman-Keuls, $p < .05$. The prelocomotor or noncrawling infants, however, had a mean, $M = 2.65$, $SE = .34$, that was lower than the means of each of the three crawling groups, Newman-Keuls, $p < .05$. Thus, performance on the object permanence task was enhanced for those infants who were crawling, even if the crawling experience was limited. There was no correlation between object permanence task performance and length of time crawling for infants in the three crawling groups, $r(56) = .04$.

Object Permanence, Locomotor Experience, and EEG

To examine relations between object permanence performance group and locomotor group with respect to EEG power values, a repeated measures MANOVA was done on the ln power values. The within subjects factors were region (frontal medial, frontal lateral, parietal, occipital) and hemisphere (left, right). The between subjects grouping factors were object permanence performance group (three levels: performing below A-not-B level, success on A-not-B at 0 delay, success on A-not-B with a 2+ s delay) and locomotor group (four levels: prelocomotor, 1–4 weeks experience, 5–8 weeks, 9+ weeks).

There were main effects for object permanence performance group, $F(2, 64) = 3.23$, $p = .046$, locomotor group, $F(3, 64) = 3.32$, $p = .025$, and region, Wilks $= .202$, approximate $F(3, 62) = 81.65$, $p \leq .001$. Interactions included object permanence group × hemisphere × region, Wilks $= .808$, approximate $F(6, 124) = 2.41$, $p = .037$.

To examine the three-way interaction among object permanence group, hemisphere, and region, separate MANOVAs were performed on the EEG power values for each region. This also allowed for interpretation of the main effects for object permanence group, locomotor group, and region that were reported in the

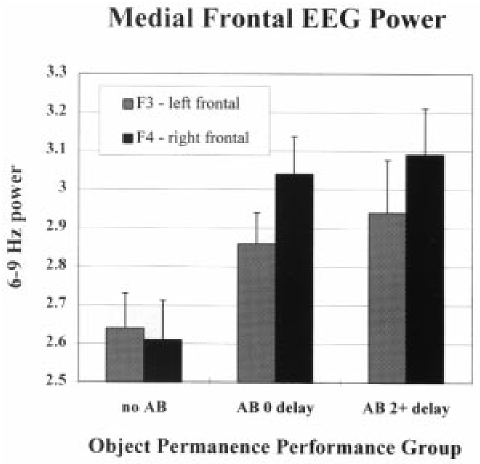

FIGURE 2 Medial frontal (F3, F4) EEG activity (ln 6–9 Hz) for the three object permanence performance groups.

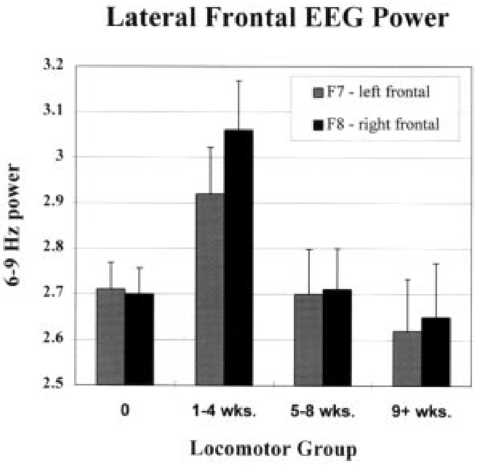

FIGURE 3 Lateral frontal (F7, F8) EEG activity (ln 6–9 Hz) for the four locomotor experience groups.

overall MANOVA analysis noted above. For the MANOVAs done for each region, object permanence performance group and locomotor group were the between subjects factors and hemisphere was the within subjects factor.

Medial Frontal. For the medial frontal (F3, F4) data, there was a main effect for object permanence performance group, $F(2, 64) = 3.57$, $p = .034$, shown in Figure 2. The group unable to do A-not-B displayed lower ln power values than the other two groups, Neuman-Keuls, $p < .05$. EEG power for the 0-delay and the 2+ second delay groups did not differ, Neuman-Keuls, $p < .05$. There was also a main effect for locomotor group, $F(3, 64) = 4.13$, $p = .030$, Infants with 1–4 weeks crawling experience displayed greater ln power values than all other locomotor groups, Neuman-Keuls, $p < .05$.

The MANOVA analysis on the medial frontal (F3, F4) data also revealed an object permanence group × hemisphere interaction, $F(2, 64) = 5.50$, $p = .006$, shown in Figure 2. The group of infants unable to do the A-not-B takes displayed equal power in both hemispheres. However, the infants successful on A-not-B at 0 delay showed differential power in the left and right hemispheres of the frontal region, $t(30) = -3.94$, $p \leq .001$, while infants able to tolerate a delay displayed a trend toward differential power in the left and right hemispheres of the frontal area, $t(18) = -1.74$, $p = .10$.

Lateral Frontal. For the lateral frontal (F7, F8) EEG there was a main effect for locomotor group, $F(3, 64) = 2.93$, $p = .040$, shown in Figure 3. The group of infants with 1–4 weeks crawling experience displayed greater ln power values than the locomotor groups with 5–8 weeks experience and 9+ weeks experience, Neuman-Keuls, $p < .05$.

Parietal. Likewise for the parietal data (P3, P4) there was a main effect for locomotor group, $F(3, 64) = 4.17$, $p = .009$, shown in Figure 4. Again, the group with 1–4 weeks crawling experience displayed greater ln power values than the other three locomotor groups, Neuman-Keuls, $p < .05$.

Occipital. For the occipital data (O1, O2) there was a main effect for object permanence group, $F(2, 64) = 4.78$, $p = .012$, shown in Figure 5. The group unable to do A-not-B displayed lower ln power values than either the group doing A-not-B at 0 delay or the group

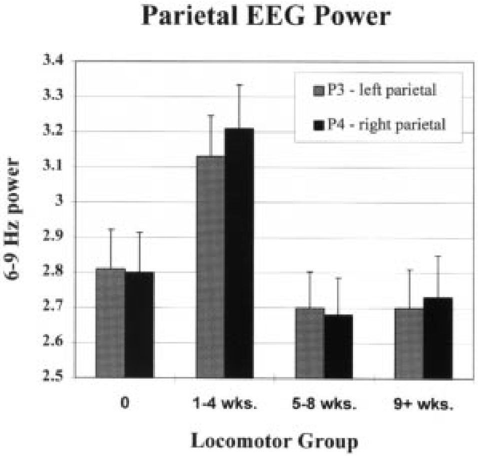

FIGURE 4 Parietal (P3, P4) EEG activity (ln 6–9 Hz) for the four locomotor experience groups.

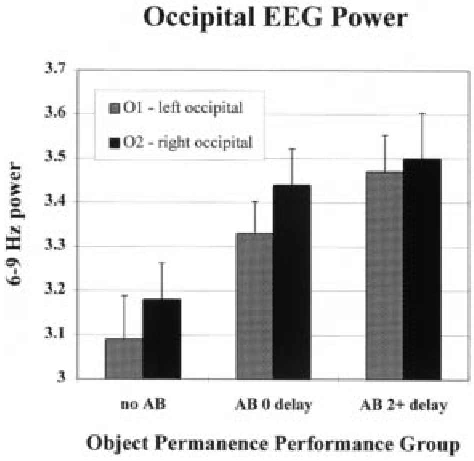

FIGURE 5 Occipital (O1, O2) EEG activity (ln 6–9 Hz) for the three object permanence performance groups.

Table 1. Model of Successful Object Permanence Performance ($n = 76$)

Model	Change in χ^2 (*df*; Significance)	Correct Classification
constant		
F3, F4*, O1, O2	15.58 (4) $p < .01$	70%
F3, F4*, O1, O2, locomotor experience*	6.79 (1), $p < .05$	67%
F3, F4, O1, O2, locomotor experience, F3 X locomotor, F4 X locomotor, O1 X locomotor, O2 X locomotor	6.03 (4), n.s.	

*$p \leq .05$, significant variables in the equation.

doing A-not-B at 2+ second delay, Neuman-Keuls, $p < .05$. There also was a main effect for hemisphere, $F(1, 64) = 5.17$, $p = .026$. For all infants in the study, there was a greater power in the right hemisphere relative to the left.

Predicting Object Permanence Performance

To test the feasibility of predicting object permanence success or failure from the amount of locomotor experience and from EEG power values, a successive set of models was tested using logistic regression. This procedure not only yields a model chi square comparable to the overall *F* test for regression, but also a classification table comparable to that done in discriminate analysis.

Because there were no EEG power value differences between infants successful on A-not-B with 0 delay and infants able to tolerate a delay on A-not-B, these two groups were combined. Thus, the dependent variable was object permanence performance (pass or fail A-not-B). Three models were tested. Based on the results of the MANOVA analyses and on the results of Bell and Fox (1992), the first model included EEG power at F3, F4, O1, and O2. Based on the results of the MANOVA analyses and on the results of Kermoian and Campos (1988), the second model added the amount of locomotor experience. The third model added interactions between each EEG lead and the amount of locomotor experience.

As seen in Table 1, the first model with the EEG power values yielded a change in model chi square from the constant and predicted success/failure at A-not-B with 70% accuracy. The significant variable in the equation was F4 EEG. The second model added the amount of locomotor experience and yielded a change in model chi square from the first model and predicted success/failure with 67% accuracy. Significant variables in the equation were F4 EEG and locomotor experience. The third model added interactions between EEG and locomotor experience, and did not yield a change in model chi square.

Identical analyses were done using only data from the infants with locomotor experience ($n = 58$). As seen in Table 2, the first model with the EEG power values yielded a change in model chi square from the constant and predicted success/failure at A-not-B with 79% accuracy. The significant variables in the equation were F3 and F4. The second model added the amount of locomotor experience and did not yield a change in model chi square from the first model. Thus, the model with interactions between EEG and locomotor experience was not examined.

DISCUSSION

In this study object permanence performance was related to individual differences in locomotor status.

Table 2. Model of Successful Object Permanence Performance for Locomotor Infants ($n = 58$)

Model	Change in χ^2 (*df*; Significance)	Correct Classification
constant		
F3*, F4*, O1, O2	23.54 (4) $p < .001$	79%
F3, F4, O1, O2, locomotor experience	0.02 (1), n.s.	

$p \leq .05$, significant variables in the equation.

Performance was enhanced for those infants who had hands-and-knees crawling experience. Previous studies have reported better performance on object permanence scales by crawling, as compared to noncrawling, infants. For example, Horobin and Acredolo (1986) and Kermoian and Campos (1988) reported that the ability to recover the hidden object was greater for infants with long-term locomotor experience. In contrast, these data showed that any amount of locomotor experience was related to better object permanence performance.

A difference between this study and those of Horobin and Acredolo (1986) and Kermoian and Campos (1988) concerned the amount of delay implemented during A-not-B testing. Horobin and Acredolo (1986) and Kermoian and Campos (1988) both employed a 3-s delay. This study implemented the delay in 2-s intervals. Neither Horobin and Acredolo nor Kermoian and Campos report how the delay was administered. In this study, it was done by counting. Therefore, it is difficult to speculate whether the difference in delay difference had any effect on the results of this study.

The data presented here provide further evidence of a relation between individual differences in frontal-brain electrical activity and performance on the A-not-B task. Corroborating the longitudinal work of Bell and Fox (1992), these data showed in an age-held-constant design that 8-month-old infants who succeeded on the A-not-B task of the object permanence scale, with or without a delay, exhibited greater power values in the frontal EEG during baseline recordings than infants unable to do the task. These data also showed differences in left and right frontal power values for infants who succeeded on the A-not-B task, with or without delay, but no hemispheric differences in frontal EEG for infants unable to do the A-not-B task. Hemispheric differences in power values in frontal EEG recordings have been associated with individual differences in emotion regulation and temperament during infancy (e.g., Bell & Fox, 1994; Calkins, Fox, & Marshall, 1996; Fox, Bell, & Jones, 1992), but have not been discussed in the context of cognitive functioning. There has been some ERP work by Molfese (e.g., Molfese & Betz, 1988) showing hemispheric differences with respect to language development with infants, but no similar work has been accomplished using EEG power. In the adult EEG literature, however, differences in frontal EEG power values have been noted with respect to cognitive processing (e.g., Crawford & Vasilescu, 1995; Davidson, Chapman, Chapman, & Henriques, 1990). Perhaps the data reported here can provide the springboard from which to explore EEG power asymmetries in relation to infant cognition.

In a review of infant EEG studies, Bell and Fox (1994) have reported that increases across time in EEG power values in the 6- to 9-Hz range have been used as an indication of brain development. Bell and Fox have also noted that longitudinal studies have reported some fluctuation in EEG power values across time; however, the overall pattern is one of increasing power. In one infant longitudinal EEG study, Mizuno, Yamaguchi, Iinuma, and Arakawa (1970) reported that spectral power was correlated with the motor milestones of sitting, standing, and walking. Likewise, the data in this study showed a correspondence between inflated EEG power in right lateral frontal and left and right parietal and the onset of locomotion. Greenough (Greenough & Black, 1992) has described a type of brain plasticity that occurs with the expectation of a species-wide maturational experience (e.g., crawling). This plasticity is manifested in synaptic overproduction or blooming prior to the event and pruning of unused synapses with increased experience after the event. Bell and Fox (1996) have used EEG coherence values to report differences in cortical organization with respect to crawling experience in infants. In that work, novice crawlers displayed greater EEG coherence between anterior and posterior recording sites than either prelocomotor infants or long-term crawlers. Thatcher (1994) has proposed that EEG coherence reflects the degree of synaptic connectivity between two scalp recording sites.

The data in this study also revealed individual differences in occipital EEG power with respect to object permanence performance. Infants unable to do A-not-B displayed lower power values than either infants doing A-not-B at 0 delay or infants doing A-not-B at 2+ second delay. Bell and Fox (1992) also reported occipital EEG differences related to object permanence performance in their longitudinal study. This finding was specific to the infants able to tolerate increasing delay in A-not-B performance across time. Those infants had greater EEG power at the left occipital recording site relative to the right occipital site at each age. This differed from the Bell and Fox (1992) *frontal* EEG findings, where *changes across age* in frontal EEG distinguished the group of infants tolerating long delay from the group of infants tolerating short delay on A-not-B.

Wilson, O-Scalaidhe, & Goldman-Rakic (1993) have used nonhuman primate data to highlight the interconnections of the occipital and frontal lobes. Both of these regions of the cortex have areas utilized for object identity and object location. Bell and Fox (1992) have shown individual differences in frontal/occipital coherence values during infancy associated with object permanence performance as well as individual differences in frontal/occipital coherence associated with locomotor onset (Bell & Fox, 1996). Development of these cortico–cortical connections between visual and memory/inhibition areas of the cortex appear to be essential for successful object permanence performance. Although the data in this study do not measure these cortico–cortical connections, the finding of frontal and occipital EEG power differences among the object permanence performance groups sets the stage for future research on dipole localization with EEG recordings from multiple scalp locations.[2]

Interestingly, these data showed no three-way interaction among locomotor experience, brain electrical activity, and object permanence performance. There were locomotor group differences in brain electrical activity at lateral frontal and parietal sites and there were object permanence performance group differences at medial frontal and occipital sites. There were, however, no Locomotor Group × Object Permanence Group interactions in any of the EEG power data. This is despite the finding of a relation between locomotor group membership and object permanence performance. It may be that there are multiple pathways to successful performance on object permanence tasks. Some infants may achieve success via locomotor experience and others may do so via brain development. A dynamic systems approach to object permanence performance may be a profitable way of examining this finding. Indeed, the dynamic systems approach has recently been used to examine the A-not-B error (Thelen & Smith, 1995) and may prove useful for examining the development of object permanence.

These data revealed differential performance on an object permanence scale by a group of healthy 8-month-old infants and highlighted the role of individual differences in successful search performance. Individual differences in locomotor experience were associated with success on an object permanence scale and individual differences in frontal and occipital EEG power values were also associated with success on object permanence. These data highlight the notion that any model of object permanence performance must account for both electrophysiological and behavioral influences.

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