Published in final edited form as:
Dev Psychol. 2010 September ; 46(5): 1363–1371. doi:10.1037/a0020185.

Developmental Progression of Looking and Reaching Performance on the A-not-B Task

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Abstract

From a neuropsychological perspective, the cognitive skills of working memory, inhibition, and attention and the maturation of the frontal lobe are requisites for successful A-not-B performance on both the looking and reaching versions of the task. This study used a longitudinal design to examine the developmental progression of infants' performance on the looking and reaching versions of the A-not-B task. Twenty infants were tested on both versions of the task once a month from 5 to 10 months of age. Infants had higher object permanence scores on the looking version of the task from 5 to 8 months, with comparable performance across response modalities at 9 and 10 months. The same pattern of performance was found on nonreversal (A) trials: Infants performed better on looking trials from 5 to 7 months and they performed equally on both response trials from 8 to 10 months. Overall, infants performed better on looking reversal (B) trials than reaching reversal trials. These data suggest that performance differences between response modalities early in development can be attributed to major differences in the maturation of brain circuitry associated with the actual task response.

Keywords

working memory; inhibition; attention; A-not-B task; frontal lobe

Within several cognitive paradigms, it has been highly debated whether reaching and looking measures of task performance are equivalent measures of the underlying cognitive construct (e.g., Baillargeon, 1995; Bell & Adams, 1999; Diamond, 1995; Hofstadter & Reznick, 1996; Munakata, 1998; Pelphrey et al., 2004; Ruffman, Slade, Sandino, & Fletcher, 2005). From a neuropsychological perspective, the cognitive skills required for the visual and manual tasks are very similar, and performance is determined by the development of particular neural substrates (e.g., Bell & Adams, 1999; Goldman-Rakic, 1987; Nelson, 1995; Pelphrey et al., 2004). According to this perspective, performance differences early in development are the direct result of immature neural pathways necessary for the motor response (i.e., reaching). Others have proposed that there are intrinsic differences in the nature of the visual and reaching response. According to this view, the reaching version of a task requires more cognitive resources than the looking version (e.g., Baillergeon, Graber, DeVos, & Black, 1990; Diamond, 1991). It has also been hypothesized that cognitive abilities become integrated with the visual system prior to the reaching system (e.g., Diamond, 1995; Hofstadter & Reznick, 1996).

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The focus of the current study was on the influence of response modality on task performance in the Piagetian A-not-B task. In the standard version of this task, infants watch as a desirable object is hidden in one of two possible locations, a brief delay is imposed, and then infants are allowed to reach. The A-not-B error occurs when infants reach to the incorrect location (A) on reversal trials (B). We chose the A-not-B task because (1) it has been the topic of extensive research and much is understood about its methodology, developmental progression, and individual differences in task performance, (2) there is converging biobehavioral evidence that the dorsolateral prefrontal cortex (DLPC) is a major contributor to task performance (e.g., EEG research with human infants: Bell, 2001, 2002, 2009; Bell & Fox, 1992, 1997; near-infrared spectroscopy with human infants: Baird et al., 2002; lesion studies with adult and infant nonhuman primates: Diamond, 1990; Diamond & Goldman-Rakic, 1989), and (3) its developmental progression (human infants: Diamond & Doar, 1989; nonhuman primate infants: Diamond, 1990) and neural correlates are very similar to the delayed response (DR) task (nonhuman primate infants: Diamond, 1990; nonhuman primate adults: Diamond & Goldman-Rakic, 1989). The DR task is methodologically identical to the A-not-B task except that reward hiding is predetermined in the DR task (i.e., independent of participants' previous responses).

In one of the first examinations of the effect of response modality on task performance when searching for a hidden object, Hofstadter and Reznick (1996) used a cross-sectional design to examine DR performance in 7-, 9-, and 11-month-old infants. They found that infants in the looking condition exhibited fewer preservative errors and a higher percentage of correct responses overall than infants in the reaching condition. Searches for infants in the looking condition, however, were not error free. Hofstadter and Reznick concluded that looking and reaching were different measures of the same cognitive construct. They proposed several alternative interpretations of performance differences based on response modality: (1) the reaching response disrupts infants' ongoing cognition and/or (2) the reaching pathway from the prefrontal cortex may be more vulnerable to preservative errors than the looking pathway. We offer an additional interpretation: Hofstadter and Reznick's findings were influenced by their between-subjects experimental design, rather than response modality.

Individual differences in performance among same-aged infants have been found in both the reaching (Bell & Fox, 1992, 1997; Clearfield, Diedrich, Smith, & Thelen, 2006; Diamond, 1985; Pushina, Orekhova, & Stroganova, 2005) and looking (Bell, 2001, 2009; Bell & Adams, 1999) versions of the A-not-B task. Matthews, Ellis, and Nelson (1996) completed the first within-subjects comparison of the effects of response modality on A-not-B task performance. Preterm and full-term infants were tested on a variety of cognitive tasks, including the looking and reaching versions of the A-not-B task, every 4 weeks from 6.5 to 14 months. Matthews et al. found that performance (i.e., the delay causing the A-not-B error) was essentially the same regardless of response modality throughout the entire testing period. They questioned the popular hypothesis (at the time) that looking was a more accurate reflection of cognition than reaching because the reaching response was contaminated by underlying representations from previous trials. Matthews et al. proposed that performance differences based on response modality resulted from infants' reach latency adding seconds to the experimental delay. [Their findings took into account the amount of time it took infants to initiate reaching (2 s), and this time was added to the A-not-B error delay time for the reaching group. It is likely that differences in response modality may have emerged at some points in development if this adjustment was not made.] The A-not-B task was not the primary focus of Matthew et al.'s investigation. Thus, the effect of response modality on additional measures of A-not-B performance (i.e., percentage of correct responses on reversal and nonreversal trials) was not reported.

Bell and Adams' (1999) primary goal was to test a neuropsychological model of A-not-B performance. Specifically, the prefrontal cognitive skills of attention, working memory, and inhibitory control that are essential for the reaching version of the task (Diamond, Prevor, Callender, & Druin, 1997) are also essential for the looking version. To this end, 8-month-old infants were tested on both the looking and reaching versions of the A-not-B task in a within-subjects design. Eight-month-olds' performance on the looking and reaching versions of the A-not-B task was not significantly different regardless of the dependent measure (i.e., object permanence scale score, percentage correct on nonreversal trials, percentage correct on reversal trials). These findings were replicated in a second experiment with one exception: For nonreversal trials, infants had a *higher* percentage of correct responses on reaching trials (57%) than looking trials (45%). Furthermore, unlike Matthews et al. (1996), performance on the looking and reaching versions of A-not-B was similar without any adjustment for the amount of time necessary for infants to initiate reaching. Recently, Pelphrey et al. (2004) found similar DR performance (i.e., correct responding on all trials) on a computerized looking version and the traditional reaching version of the task when using a within-subject design with 6-, 8-, 10-, and 12-month-olds[1]. (Response modality was examined using a within-subjects design and age was examined using a between-subjects design.) Thus, a within-subjects design is critical when examining the effect of response modality on search task performance.

The aim of the present study was to examine the developmental progression of looking and reaching performance in the A-not-B task using a longitudinal, within-subjects design. Many infants fail to reach for a hidden object prior to 7 months of age (Diamond, 1985). Because the looking response matures prior to the reaching response, it is likely that the 8-month-olds in Bell and Adams' (1999) study exhibited similar performance in both modalities because the motor response of reaching had "caught up" with the looking response. Bell and Adams proposed that if the looking response matures faster than the reaching response, then this maturational process should be exhibited in a longitudinal design. They also hypothesized that looking performance would be superior to reaching performance prior to 7 or 8 months of age, but after this point in development, performance would be similar across modality. To this end, we tested a group of 20 infants once a month from 5 to 10 months of age on both the reaching and looking versions of the A-not-B task.

Method

Participants

Twenty healthy full-term infants (6 girls, 14 boys; 17 Caucasian, 2 African American, 1 Hispanic) were participants in this longitudinal study. Infants were born to middle- and upper-middle-class parents and English was the primary language spoken in the home. All parents had at least a high school diploma (mothers: 10% high school diploma, 5% technical degree; 70% bachelor's degree, 15% graduate degree; fathers: 10% high school diploma, 5% technical degree, 65% bachelor's degree, 20% graduate degree). Mothers were approximately 30 years old (range 22–40) and fathers were approximately 31 years old (range 22–45). Infants were recruited via birth announcements placed in local Blacksburg and Christiansburg, Virginia newspapers. All infants were born within 15 days of their

[1]It should be noted that reaching versions of the A-not-B task probably have more similarities across laboratories than looking versions of the A-not-B task. Looking versions of the A-not-B task differ in whether (1) they are administered via computer (Pelphrey et al., 2004) or experimenter (Bell & Adams, 1999; Hofstadter & Reznick, 1996; Matthews et al., 1996), (2) the stimuli are silent (Hofstadter & Reznick, 1996) or noise-making (Bell & Adams, 1999; Matthews et al., 1996; Pelphrey et al., 2004) prior to hiding, (3) the hidden stimuli are social (Pelphrey et al., 2004) or nonsocial (Bell & Adams, 1999; Hofstadter & Reznick, 1996; Matthews et al., 1996), and (5) the hidden stimuli are handle be the infant following a correct looking response (Hofstadter & Reznick, 1996) or not (Bell & Adams, 1999; Matthews et al., 1996; Pelphrey et al., 2004). Whether the aforementioned variations in looking versions of the A-not-B task produce comparable results is an empirical question.

calculated due dates and were healthy at the time of testing. Infants were seen in the laboratory monthly from 5 until 10 months of age, for a total of six sessions. Infants were seen within 15 days of their month "birthday." One infant began the study when he was 6 months. Parents were paid $20 for each monthly visit to the research lab.

Infants were assessed on both the classic reaching version and a looking version of the A-not-B object permanence task in this within-subjects design (see Bell & Adams, 1999). Order of modality assessment was counter-balanced among infants at the same age and across age for the same infant. The same experimenter assessed each infant on both versions of the task at each monthly assessment.

Reaching Version of the A-not-B Task

Details of the reaching assessment are similar to those described by Bell and Adams (1999). Infants were tested on an adapted version of Kermoian and Campos's (1988) object permanence scale. This scale was constructed to classify a wide range of object permanence performance:

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.

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 parent's lap at a table. The experimenter was seated opposite the infant and offered the infant a small attractive toy, such as a brightly colored rattle or squeaky toy. After the infant manipulated the toy briefly, the experimenter removed the toy and administered object permanence scale items 1–3 using the following procedures:

1. *Finding an object that was partially covered:* The experimenter 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 that was completely covered:* The experimenter 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 that was completely covered with a single screen in two places:* The experimenter 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 experimenter regained the attention 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. Infants were rewarded for a correct reach with praises and clapping from the experimenter. They also were allowed to briefly manipulate the toy prior to the next hiding. Infants were not allowed to manipulate the toy after incorrect reaches.

Upon successful completion of the object permanence scale item 3 above, the A-not- B procedure began. Items 4–6 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., identical covers and backgrounds, two hiding locations horizontally oriented, and object hidden in the same location on all A trials and then hidden at the other location, the B trial (Marcovitch & Zelazo, 1999; Wellman, Cross, & Bartsch, 1986). For this study, the A-not-B task apparatus was a white table that measured 76.5 cm (L) X 46.4 cm (W) X 10.8 cm (D). Embedded in the table were two wells 9.5 cm in diameter, 12.7 cm deep, and 32.3 cm apart from center to center. Blue fabric cloths used to cover the wells measured 20 cm^2. The table height allowed the infant to see inside the hiding wells while seated on parent's lap.

The A-not-B task table was placed in front of the infant so that the center of the apparatus 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. The experimenter placed the toy in one of the wells and simultaneously covered each well with a blue cloth (Diamond, Cruttenden, & Neiderman, 1994). After two successful retrievals at side A, the toy was then hidden in the opposite well B. Infants who successfully recovered the toy from the B well on two out of three A–A–B trials (i.e., did not make the A-not-B error) were then tested with a 2-s delay. Subsequent delays were initiated until the infant made the A-not-B error on two out of three trials at any given delay. Delay was incremented in 2-s intervals throughout the study. To be declared competent at any given delay, each infant was required to successfully retrieve the toy from the B well in two out of three A–A–B trials.

A distracter was employed after each hiding of the toy to break visual fixation of the hidden object (Bell & Adams, 1999; Bell & Fox, 1992, 1997; Diamond, 1985). For scale items 1–3 and for the 0 delay condition for A-not-B, the mother held the infant's hands while the experimenter called the infant's name to briefly divert the infant's gaze from the hiding site. Immediately afterwards, the experimenter asked, "Where's the toy?" The procedure was identical for the delay conditions, except the experimenter also clapped her hands and counted out the delay period to divert the infant's gaze from the well. "Where's the toy?" was the cue to the mother to release her infant's hands and permit her child to search. Diamond (1985) has argued that a distracter is necessary because visual fixation to the correct well can be used to simplify the A-not-B task. Thus, the 0 delay scale item 4 did have a slight delay as the infant's gaze was broken from the hiding site and the question asked.

Object permanence testing was stopped after the infant failed two out of three trials at a particular task on the object permanence scale or until the infant achieved success on two out of three trials at a 4-s delay. Uzgiris and Hunt (1975) have demonstrated the ordinal nature of object permanence item 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 (i.e., there was *no* A-not-B error) with 0 delay received a score of 4.

Although behavioral coding was necessarily accomplished by the experimenter during the course of assessment (i.e., the pattern of hidings was dependent on infant performance), additional coding of the reaching object permanence scale was done from the videotape of the laboratory session by undergraduate research assistants. This additional coding was accomplished as a reliability check on the pattern of hidings used by the experimenter and involved coding of each infant's performance by both coders. The percentage of agreement between the two coders for the 20 infants in the study was 100%.

Looking Version of the A-not-B Task

In this version of the task, the infant "searched" for the hidden toy with eyes rather than hands. The table from the reaching version of task had two side panels that created a smooth surface (i.e., covered the hiding wells) for the looking version of the task. The task table was placed in front of the infant so that the center of the table (marked by the seam of the two panels covering the hiding wells) was at the infant's midline. Two bright orange or blue plastic tubs (diameter: 17 cm; depth: 11 cm) were equidistant from midline. Two clear pieces of tape marked where the centers of the tubs should be when placed upside down over the A and B hiding sites. These markers positioned the tubs 35 cm apart. The experimenter was seated on the opposite side of the table facing the infant and parent. The infant sat on the parent's lap 1.1 m from the edge of the testing table. The hiding event for the looking task was comparable to the reaching task. The experimenter manipulated a toy, placed it on the table, and then simultaneously placed two bright orange or blue plastic tubs on the table. One tub covered the toy, and the other covered the alternative hiding site.

The experimenter administered the task identically to the administration of the reaching version of the task except for a few modifications (Bell & Adams, 1999). The primary difference was that the infant's eye movements were used as the performance behavior, as opposed to the infant's reaching and uncovering one of the wells. The direction of the infant's first eye movement after being brought to midline was scored as either correct or incorrect. The video camera was placed behind and above the experimenter's head and focused so as to maintain a close-up view of the infant's face.

Noise-making toys were used to maintain the infant's attention to the task during the hidings. Because infants were not allowed to manipulate the toys themselves, the experience they received from the toy had to provide the impetus to continue to search for the toy. (We ensured that the noise-making toys were silent when they were hidden.) Infants were rewarded for a correct eye movement with praise and clapping from the experimenter. After an incorrect eye movement, the experimenter sighed and blandly told the infant, "It's over here."

The distracter was essential during the looking version as the infant must disengage fixation before the eye movement can be made back to the hiding site. Under delay conditions, it was unnecessary for the mother to hold the infant's hands because the distance from the infant to the tubs was 1.1 m. None of the infants strained toward the hiding tubs. Immediately after diverting the infant's gaze, the experimenter used the same verbal cue from the reaching version by asking, "Where's the toy?"

The coding scheme for the looking version was the same as for the reaching version. Although behavioral coding was necessarily accomplished by the experimenter in the course of assessment (i.e., the pattern of hidings was dependent on infant performance), additional coding of looking object permanence scale was done from the videotape of the laboratory session by undergraduate research assistants. This additional coding was accomplished as a reliability check on the pattern of hidings used by the experimenter and involved coding of each infant's performance by both coders. The percentage of agreement between the two coders for the 20 infants in the study was 96.6%. The four disagreements in coding were discussed by the authors, with final determination of object permanence reaching score made by the second author.

Results

Data were missing for two infants at 5 months of age: One did not enter the study until 6 months of age, and the other was too fussy for the reaching task to be administered. To avoid having these two participants dropped from all of the multivariate analyses because of their missing data, values of the missed session for each infant were interpolated from the data collected at the session adjacent to the missed session (i.e., 6 month visit). The interpolation procedure was chosen, as opposed to substituting the mean value of all subjects at the first visit, because the interpolation procedure yielded a substituted value that more closely resembles the individual infant's initial performance level.

Object permanence performance level

A 2 (Modality) × 6 (Age) repeated measures multivariate analysis of variance (MANOVA) revealed a main effect for Modality, $F(1, 19) = 20.82$, $p < .001$, $\eta_p^2 = .52$, a main effect for Age, $F(5, 15) = 31.14$, $p < .001$, $\eta_p^2 = .91$, and a marginally significant Modality × Age interaction, $F(5, 15) = 2.85$, $p = .053$, $\eta_p^2 = .49$ (see Figure 1). Paired samples *t*-tests comparing looking and reaching performance were completed for each age where the SE bars were not overlapping. Because of the multiple *t*-tests, the adjusted *p* value was ≤ .013 (.05/4 = .013). *T*-tests indicated that from 5 to 8 months of age higher object permanence scores were obtained for the looking response as compared to the reaching response (all *t*'s ≥ 2.90, *p*'s ≤ .01).

Table 1 provides the relative performance of individual infants on the looking and reaching scales. Between four and six infants (20–30%) had duplicate scores on looking and reaching versions of the task at each age. As infants aged, fewer infants scored higher on the looking version relative reaching version; 14 infants (70%) at 5 months and 10 infants (50%) at 10 months. The opposite pattern is noted for the number of infants scoring higher on the reaching version relative to the looking version: two infants (10%) at 5 months compared to five infants (25%) at 10 months. Further examination revealed that at each age between 10 and 15 infants (50–75%) had looking and reaching scores that were within one scale level of each other. As infants became older, fewer infants scored at least two scale levels higher on the looking version relative the reaching version; 8 infants (40%) at 5 months compared to four infants (20%) at 10 months. This pattern was reversed when examining the number of infants that scored at least two scale levels higher on the reaching version relative to the looking version; no infants at 5 months versus three infants (15%) at 10 months.

Performance on nonreversal and reversal trials

Inspection of the infants' performance on each individual A or B hiding allowed analysis of the correct response on nonreversal (A) and reversal (B) trials (e.g., Bell & Adams, 1999; Hofstadter & Reznick, 1996). A 2 (Trial Type: nonreversal or reversal) × 2 (Modality) × 6 (Age) repeated measures MANOVA of the proportion of correct responses revealed a main effect for Trial Type, $F(1, 19) = 393.75$, $p < .001$, $\eta_p^2 = .95$, a main effect for Modality, $F(1, 19) = 31.80$, $p < .001$, $\eta_p^2 = .63$, a main effect for Age, $F(5, 15) = 16.27$, $p < .001$, $\eta_p^2 = .84$, and a Modality × Age interaction, $F(5, 15) = 4.42$, $p = .011$, $\eta_p^2 = .60$. These main effects and two-way interactions were superseded by a Trial Type × Modality × Age interaction, $F(5, 15) = 6.28$, $p = .002$, $\eta_p^2 = .68$ (see Figure 2).

For ease in examining the three-way interaction among trial type, response modality, and age, separate MANOVAs were performed over the proportion of correct response for looking and reaching modalities. A 2 (Trial Type) × 6 (Age) repeated measures MANOVA of the proportion of correct responses for the looking version of the task yielded main effects for Trial Type, $F(1, 19) = 81.65$, $p < .001$, $\eta_p^2 = .81$, and Age, $F(5, 15) = 4.40$, $p = .012$,

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$\eta_p^2 = .59$. There was no Trial Type x Age interaction, $p = .12$. Inspection of the means in Figure 2 shows that performance on nonreversal looking trials was higher than performance on reversal looking trials.

A 2 (Trial Type) × 6 (Age) repeated measures MANOVA of the proportion of correct responses on the reaching version of the task indicated a main effect for Trial Type, $F(1, 19) = 57.78$, $p < .001$, $\eta_p^2 = .75$, a main effect for Age, $F(5, 15) = 14.71$, $p < .001$, $\eta_p^2 = .83$, and a Trial Type × Age interaction, $F(5, 15) = 13.83$, $p < .001$, $\eta_p^2 = .82$. Paired samples t-tests comparing performance on nonreversal trials and reversal trials on the reaching version were completed for each age where the SE bars were not overlapping (see Figure 2). Because of the multiple t-tests, the adjusted p value was ≤ .013 (.05/4 = .013). T-tests indicated that infants performed better on nonreversal trials, as compared to reversal trials, from 7 to 10 months of age (all t's ≥ 3.02, p's ≤ .01).

Additional analyses were completed to examine performance differences based on response modality on both nonreversal and reversal trials. A 2 (Modality) × 6 (Age) repeated measures MANOVA of the proportion of correct responses on nonreversal trials revealed a main effect for Modality, $F(1, 19) = 24.16$, $p < .001$, $\eta_p^2 = .56$, a main effect for Age, $F(5, 15) = 33.90$, $p < .001$, $\eta_p^2 = .92$, and a Modality × Age interaction, $F(5, 15) = 8.03$, $p = .001$, $\eta_p^2 = .73$. Paired samples t-tests comparing looking and reaching performance on nonreversal trials were completed for each age where the SE bars were not overlapping (see Figure 2). Because of the multiple t-tests, the adjusted p value was ≤ .017 (.05/3 = .017). T-tests indicated that infants' performance on nonreversal trials was better on the looking version than the reaching version of the task from 5 to 7 months of age (all t's ≥ 2.89, p's ≤ .01).

A 2 (Modality) × 6 (Age) repeated measures MANOVA of the proportion of correct responses on reversal trials revealed main effects for Modality, $F(1, 19) = 6.31$, $p = .021$, $\eta_p^2 = .25$, and Age, $F(5, 15) = 6.51$, $p = .002$, $\eta_p^2 = .69$. There was no Modality × Age interaction, $p = .38$. Overall, performance on reversal looking trials, $M = .328$, 95% CI [.271, .384], was higher than performance on reversal reaching trials, $M = .242$, 95% CI [.185, .298]. Although the Modality × Age interaction was not significant, inspection of the means in Figure 2 reveals that SE bars were overlapping at all ages except 5 and 7 months.

Cross-sectional comparison at 8 months

To examine whether repeated testing affected infants' performance on either the looking and/or reaching versions of the A-not-B task, we compared the performance of infants in our longitudinal study at 8 months of age to the performance of 8-month-olds from Bell and Adams' (1999) study (Experiments 1 and 2). This comparison was ideal because the methodologies and performance measures were identical across studies.

Bell and Adams (1999) found equivalent object permanence scores across response modalities at 8 months of age, 1 month earlier than found in the present study. A direct comparison at 8 months reveals that although infants' reaching scores were similar in both studies ($M = 2.90$; Bell & Adams: $M = 3.11$ and 3.02), infants in our longitudinal study had higher looking scores ($M = 3.60$; Bell & Adams: $M = 3.02$ and 2.70). A similar pattern was found when comparing the percentage of correct nonreversal (A) trials between studies. Although both studies found equivalent performance across response modalities at 8 months of age, infants in our longitudinal study had a higher percentage of correct looking trials (62%; Bell & Adams: 55% and 45%). In both studies, infants reached correctly 57% on the time on nonreversal trials. The only measure that was not affected by repeated testing was the percentage of correct reversal (B) trials. In both studies, infants exhibited equivalent performance across response modality at 8 months of age, and a direct comparison between studies revealed no differences in the percentage of correct looking or reaching trials.

Discussion

Our longitudinal data are compatible with a neuropsychological perspective: The cognitive skills required for the looking and reaching versions of the A-not-B task are very similar. Performance is likely determined in part by the development of the prefrontal cortex as shown by converging evidence from EEG (e.g., Bell, 2001; Bell & Fox, 1992), near-infrared spectroscopy (Baird et al., 2002), and behavioral neuroscience (Diamond, 1990; Diamond & Goldman-Rakic, 1989) research. Infants initially exhibited superior performance on the looking version of the A-not-B task, and subsequently exhibited comparable performance across response modalities. These data demonstrate that performance differences between response modalities early in development can be attributed to major differences in the maturation of brain circuitry associated with the actual task response. Looking responses are exhibited by infants very early in development, with even newborn infants visually fixating to interesting stimuli (e.g., Banks & Solapatek, 1983). Reaching responses, in contrast, are not consistently exhibited until the 3rd or 4th month (e.g., Thelen, Corbetta, & Spencer, 1996), and they continue to be characterized as being poorly controlled (e.g., variable speeds, lots of starts and stops, not direct) during the 5th month (e.g., Clearfield et al., 2006; Thelen et al.,1996). Thus, as infants' reaching abilities and skills are developing, performance on the looking version of the task is better than performance on the reaching version. By 8 or 9 months of age, their reaching behavior is more developed and skilled, and performance is comparable across response modalities.

Within each response modality, we examined several different response measures: object permanence scale score, percentage correct on reversal trials, and percentage correct on nonreversal trials. Comparable, but slightly different developmental patterns were found when considering each of these performance measures. Infants had higher object permanence scale scores on the looking version of the task from 5 to 8 months of age, with equivalent performance at 9 and 10 months of age (Figure 1). The developmental progression on nonreversal (A) trials was similar: Infants looked correctly more often than they reached correctly from 5 to 7 months and they performed equally on both measures from 8 to 10 months (Figure 2). Overall, infants performed better on looking reversal (B) trials than reaching reversal trials. However, visual inspection of Figure 2 suggests that the relationship between modality and performance on reversal trials may not be straightforward. (Although the Modality x Age interaction was not significant, SE bars overlap at every age except 5 and 7 months.)

The development of visually-guided reaching has been systematically examined by Thelen and colleagues. In the first study to provide detailed information about the kinematics of reaching over the first year of life, Thelen et al. (1996) detailed four infants' reaching development week-by-week. Infants exhibited dramatic improvements in their reaching behaviors between 30–36 weeks of age (approx 6.9–8.3 months). More recently, Clearfield et al. (2006) tracked two infants' reaching motor development week-by-week and also tested their performance on a non-hidden object reaching version of the A-not-B task month-by-month. Their findings confirmed previous evidence from Thelen et al. (1996) that early reaches were not straight, smooth (i.e., lots of starts and stops), or stable (i.e., variable speeds). In fact, when tested on the A-not-B task at 5 months, one infant was unable to reach and the other refused to reach. Together, these studies reveal that the development of visually-guided reaching is protracted and that there are individual differences in the onset of stable reaching.

Although we have proposed that performance differences between looking and reaching responses early in development are likely the result of differences in the maturation of the actual task response, it is plausible that additional factors might contribute to the reaching-looking performance dissociation. According to a cognitive capacity account of infant perseveration, infants have a finite amount of cognitive and attentional resources, and performance depends on the allocation of these resources (Berger, 2004). Berger hypothesized that a task's motoric demands might also require the allocation of cognitive and attentional resources. In fact, motoric demands can require the same amount of resources as cognitive demands. Thus, increased motoric task demands tax an infant's finite cognitive resources and result in poorer task performance. Berger examined this hypothesis by testing 13-month-old walking infants on a non-hidden object version of the A-not-B task. Motoric task demands were varied by having infants traverse either flat ground (low demand) or descending stairs (high demand). Infants exhibited perseverative responding under conditions of high, but not low, motoric task demands.

The cognitive capacity account of perseveration could also account for the reaching-looking performance dissociation early in development: the looking response requires fewer task demands than the reaching response. Diamond (1991) has proposed additional differences in the cognitive demands of the looking and reaching versions of the A-not-B task. The looking task requires memory of the hiding location and a visual response. The reaching task, in contrast, requires memory of the hiding location, planning of a means-ends action sequence, and a reaching response. Thus, not only is the reaching response itself more complicated than the looking response, but the reaching response also requires an additional planning component. Although Diamond's hypothesis is useful in understanding the looking-reaching dissociation early in development, it is unclear whether this hypothesis can also account for equivalent performance across response modalities later in development.

Munakata (1998) has attempted to explain developmental differences between reaching and looking performance using the notion of graded representations. Munakata proposes that reaching measures of performance require stronger, later developing mental representations than looking measures. Thus, weaker representations are sufficient for accurate performance when looking measures are used early in development. Munakata also developed the parallel distributed processing (PDP) model, a simulation model, to test numerous hypotheses about the A-not-B task. To simulate the reaching-looking performance dissociation, the model includes a lower frequency of reaching. Accordingly, the reaching system has fewer opportunities to respond and update the graded representation on B trials as the looking system.

The PDP model of the reaching-looking performance dissociation predicts that there is a point early in development when infants perform better on reversal trials when measured by reaching as compared to looking and that later in development performance on reversal trials is similar across response modalities. Examination of Figure 2 does not reveal superior reaching performance on reversal trials in early development. Munakata's PDP model also predicts near asymptotic performance on nonreversal trials for both response measures across development. Our data fail to support this prediction: From 5 to 7 months infants performed better on nonreversal trials when the overt response was looking as compared to reaching. Furthermore, infants' performance on nonreversal trials never reached asymptotic performance regardless of response modality.

In the present study, infants exhibited superior performance when looking measures were examined early in development and equivalent performance across response modalities later in development. We have presented several possible accounts for this looking-reaching performance dissociation early in development. We posit that the protracted development of the reaching response and corresponding neural connections are central to this performance dissociation early in development. In fact, Berger's (2004) notion of high and low motoric demands would parallel the development of stable reaching and equivalent performance across response modality.

Diamond (1985) found that when infants were tested on the reaching version of the A-not-B task every 2 weeks from 6.5 to 12 months of age, they made the A-not-B error after delays that were 1.5 to 2 s longer than same-aged infants tested on a single occasion. To examine the influence of repeated testing on infants' performance in our longitudinal investigation, we compared our findings to Bell and Adams' (1999). For the looking version of the task, 8-month-olds in our study had higher object permanence scores and higher percentages of correct responses on nonreversal trials than 8-month-olds from Bell and Adams' study. This enhanced performance is most likely the result of repeated testing. However, we cannot rule out the possible contribution of individual differences to between-study discrepancies in looking performance.

The absence of repeated testing effects on the motor response at 8 months of age is intriguing. We hypothesized that, at younger ages, the maturation of the circuitry associated with the actual motor response was responsible for modality-based performance differences. Although all infants received two location looking trials at 5 to 7 months of age, only 10%, 25%, and 60% of infants at 5, 6, and 7 months, respectively, received two location reaching trials. Accordingly, if younger infants are unable to make the motor reaching response, then they have fewer opportunities to benefit from repeated testing than when looking is the primary measure of interest.

From an individual differences perspective, direct comparisons of performance on looking and reaching scale measures are intriguing (Table 1). For instance, although two infants scored higher on the looking version of the task at every monthly visit from 5 to 10 months, no infant consistently scored higher on the reaching version of the task. Furthermore, at each monthly visit, between 50 and 75% of infants had looking and reaching scale measures that were within one scale score of each other. How might these infants differ from infants whose reaching and looking scale scores are two or more scale scores apart? Electrophysiological data could be used to further examine these types of group differences in A-not-B performance.

Electroencephalography (EEG) has been used to examine performance differences on both the looking and reaching versions of the A-not-B task during infancy. Due to motor artifacts during the response phase, performance on the reaching version of the task can only be examined during the baseline phase (e.g., Bell & Fox, 1992, 1997). The development of the looking version of the A-not-B task has allowed for on-task comparisons of task performance (Bell, 2001, 2002, 2009). EEG coherence and EEG power are both associated with task performance. In a study with 8-month-olds, for example, Bell (2001) found that high performers on the object permanence scale (scores 4 to 6) exhibited baseline to task changes in EEG, but low performers (scores 0 to 3) did not. To this end, future A-not-B research could examine the influence of response modality on task performance by analyzing both baseline and on-task EEG. This strategy would allow for a cognitive neuroscience interpretation of individual differences in A-not-B performance based on response modality.

Initial interest in comparing looking and reaching measures of A-not-B performance stemmed from anecdotal evidence that on reversal trials, infants would occasionally look to the correct well (B) while reaching to the incorrect well (A) (Diamond, 1985). All within-subject comparisons of performance on looking and reaching versions of the task, including the present study, have found comparable performance by 8 to 9 months of age (Bell & Adam, 1999; Matthews et al., 1996; Pelphrey et al., 2004). Furthermore, a comparison of 8- to 12-month-olds' glancing and reaching on reversal trials found that infants were not more likely to glance correctly than they were to reach correctly (Ruffman et al., 2005). Recently, Kagan (2008) emphasized the need for multiple measures when discussing infants' cognitive capacities, such as object permanence. He states that, "…it is rare, in any scientific domain, for a single measure to reveal all that is necessary to understand a phenomenon." (p. 1620). Although Diamond's anecdote was not supported by subsequent investigations, this line of research has led to a more complete understanding of object permanence and the development of a looking version of the A-not-B task. Researchers can use the looking task to examine changes in frontal electrical activity during cognitive processing (Bell, 2001, 2002, 2009). This focus on brain-behavior relations has the potential to provide valuable information regarding the early development of complex cognitive functions.

Acknowledgments

Data collection was supported in part by a Millennium Grant from the College of Arts and Sciences at Virginia Tech. This research also was supported by grants R01 HD049878 from the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development (NICHD) awarded to Martha Ann Bell. The content of this manuscript is solely the responsibility of the authors and does not necessarily represent the official views of the NICHD or the National Institutes of Health. The assistance of Jonathan E. Roberts and numerous undergraduate research assistants is gratefully acknowledged.

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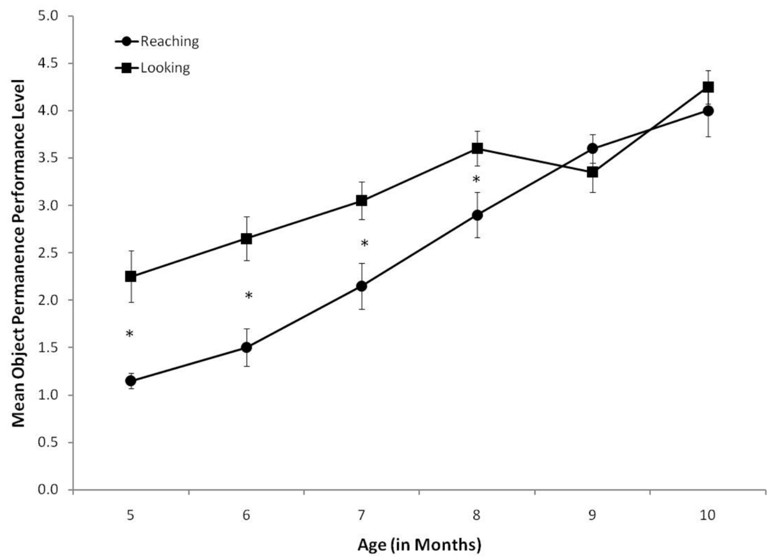

Figure 1.

Mean object permanence scale score (and SE) on the looking and reaching versions of the A-not-B task from 5 to 10 months of age.

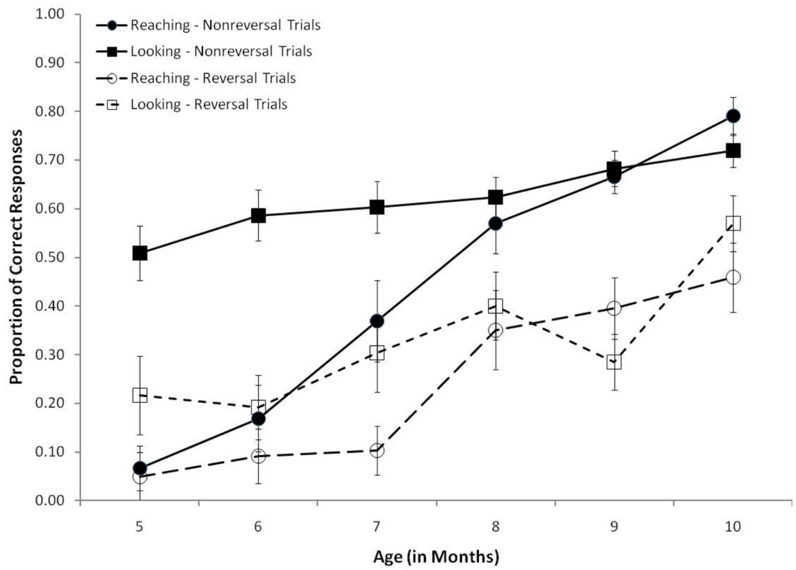

Figure 2.
Proportion of correct responses (and SE) on nonreversal and reversal trials on looking and reaching versions of the A-not-B task from 5 to 10 months of age.

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Table 1

Comparison of Individual Infants' Looking and Reaching Object Permanence Scale Scores

Participant	5 mo	6 mo	7 mo	8 mo	9 mo	10 mo
1	L1	=	L2	=	R3	=
2	L1	L1	L1	L2	R1	R1
3	R1	L2	L2	=	=	L1
4	L3	L2	L2	L1	R2	R2
5	L2	=	=	=	=	L1
6	L3	L3	L1	=	L2	L1
7	=	R1	L2	L1	L1	L2
8	L1	L3	L1	L2	R1	=
9	L2	L2	L1	L2	L1	L2
10	L2	L2	L1	L1	R1	=
11	L2	L2	=	L1	R1	R3
12	=	R1	L1	R1	=	=
13	L1	=	L1	L1	=	L2
14	=	=	=	R2	R2	L1
15	L1	L2	L1	=	L1	L1
16	=	=	=	=	R1	R1
17	R1	L1	=	L1	=	L2
18	L2	L2	R1	L1	R1	R2
19	L3	L1	L1	L2	L2	=
20	L1	L2	L2	L2	L1	L1
Total L	**14**	**13**	**14**	**12**	**6**	**10**
Total =	**4**	**5**	**5**	**6**	**5**	**5**
Total R	**2**	**2**	**1**	**2**	**9**	**5**
Total L1	*6*	*3*	*9*	*7*	*4*	*6*
Total L2	*5*	*8*	*5*	*5*	*2*	*4*
Total L3	*3*	*2*	*0*	*0*	*0*	*0*
Total R1	*2*	*2*	*1*	*1*	*6*	*2*

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Participant	5 mo	6 mo	7 mo	8 mo	9 mo	10 mo
Total R2	*0*	*0*	*0*	*1*	*2*	*2*
Total R3	*0*	*0*	*0*	*0*	*1*	*1*

Note. L = looking; R = reaching; L1 = looking 1 point > reaching; L2 = looking 2 points > reaching; L3 = looking 3 points > reaching; R1 = reaching 1 point > looking; R2 = reaching 2 points > looking; R3 = reaching 3 points > looking; “=” = looking and reaching are equal.