

# Locomotor Status and the Development of Spatial Search Skills

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BAI, DINA L., and BERTENTHAL, BENNETT I. *Locomotor Status and the Development of Spatial Search Skills*. CHILD DEVELOPMENT, 1992, 63, 215–226. The principal objective of this experiment was to investigate whether previous reports of a relation between locomotor status and stage 4 object permanence performance generalized to performance on a different object localization task. A secondary objective was to evaluate the contribution of visual tracking as a mediating variable in the relation between locomotor experience and search performance. Precrawling ( $n = 20$ ), crawling ( $n = 10$ ), and creeping ( $n = 18$ ) infants ( $M = 33$  weeks old) were tested using a search task in which either they or the hiding containers were rotated  $180^\circ$  before search was permitted. The results revealed that locomotor status was related to search performance following a displacement of the infant, but not following a displacement of the containers. Moreover, visual tracking of the correct container was not related to locomotor status, even though it was related to search performance. These findings suggest that the effects of locomotor experience on infants' search performance are quite specific and are mediated by a variety of factors that do not necessarily generalize across search tasks.

Infants show dramatic improvements in their ability to find previously seen objects during the second half of the first year of life (Bremner, 1985; Harris, 1983). Prior to 8 or 9 months of age, infants are rarely successful in searching for a hidden object following a displacement of the object or themselves. Their responses suggest that they encode the position of the object using a body-centered frame of reference that is not updated during the displacement (Acredolo, 1978; Bremner & Bryant, 1977). Thus, an object that is initially localized to the right, and then displaced to the infant's left, is searched for only to the right even when the infant observes the displacement. The situation changes around 8 to 9 months of age, when infants begin to show correct search for an object following a displacement (Acredolo & Evans, 1980; Bremner, 1978; Goldfield & Dickerson, 1981). A number of investigators speculate that this developmental shift is functionally related to the new demands placed upon the infant following the onset of locomotion (Acredolo, 1978; Bertenthal, Campos, & Barrett, 1984;

Bremner, 1978; Bremner & Bryant, 1985; Campos & Bertenthal, 1989; Goldfield & Dickerson, 1981).

Logically, this prediction seems quite compelling. Crawling demands a new level of vigilance by the infant. Prior to independent locomotion, the infant moves to a new location only when passively transported. During these movements, attention to where one is going is not essential, since displacements are under external control. This situation changes dramatically with the onset of independent locomotion. Now it is necessary for the infant to monitor carefully his or her own actions in order to avoid colliding with other objects, falling off of high places, etc. A number of investigators conjecture that this increased vigilance while locomoting will generalize to other important changes in the relation between the infant and the spatial layout (Campos & Bertenthal, 1989; Horobin & Acredolo, 1986; Kermoian & Campos, 1988). In particular, infants are more likely to detect changes in their position relative to other objects. The detection

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of these changes is a necessary prerequisite for the reorganization of spatial coding by infants.

Furthermore, it is important to recognize that crawling introduces functional changes in the relation of the infant to the environment (see Bremner, 1978). Specifically, the stability of the infant's spatial orientation relative to other objects in the spatial layout is significantly disrupted with the onset of crawling. Prior to the acquisition of this skill, infants typically remain in the same location for extended periods of time. Thus, coding the position of an object using a body-centered frame of reference is generally successful. Once an infant begins to crawl, the probability that an object's position relative to the infant will persist for any extended period of time becomes quite low. As a consequence, body-centered coding of an object's position will prove increasingly inadequate for relocalizing the object. Gradually, the infant learns that using a stable landmark will offer a more successful strategy for relocalizing objects.

### *Empirical Evidence*

Surprisingly, the empirical evidence relevant to the predicted relation between locomotor experience and object localization is quite sparse. In one of the few studies examining this issue, Kermoian and Campos (1988) tested locomotor, prelocomotor, and prelocomotor infants who used "walkers" on a series of tasks corresponding to an object permanence scale (Kagan, Kearsley, & Zelazo, 1978). The principal finding was that locomotor infants and prelocomotor infants with walker experience passed more of the items than did prelocomotor infants. In particular, infants with the greatest amount of locomotor experience (i.e., 9 weeks) passed a two-position hiding task (i.e., A, not B task), whereas prelocomotor infants were not able to pass even a task involving a single visible displacement.

A similar finding was reported by Horobin and Acredolo (1986) who tested infants on an A, not B, object permanence hiding task, and found that performance was correct more consistently among those infants with greater locomotor experience. In addition, these investigators measured infants' visual tracking during the hiding portion of the task and found that *sustained visual tracking* of the correct target increased in frequency with locomotor experience, and was also a significant predictor of search performance. It was concluded that performance improves

with locomotor experience because visual tracking also improves with locomotor experience.

Although the preceding two studies provide fairly compelling evidence that locomotor experience is systematically related to one particular search task, it is not at all clear that this conclusion generalizes to other search tasks. In particular, the search task used in these two studies was modeled on Piaget's stage 4 object permanence task. As such, the task involved a search for a visibly displaced object. Another task that is commonly used for assessing search performance in 7–9-month-old infants involves displacement of the self or the object following the *hiding* of the object in a container (this task will be referred to as self/object displacement throughout the remainder of the paper). In this task, the object is first hidden in one of two locations that are equidistant, but on opposite sides of the infant. Infants are then given an opportunity to search for the hidden object only after they or the containers hiding the object are rotated 180° around the room. Interestingly, this task shares more in common with Piaget's stage 6 (single invisible displacement) task than it does with Piaget's stage 4 task (Bertenthal & Fischer, 1983; Bremner & Bryant, 1985). It is thus not clear that any relation observed between search performance and locomotor experience on the stage 4 object permanence task would necessarily generalize to the more difficult search task. Paradoxically, most of the speculation concerning a relation between locomotor experience and search performance has been motivated by infants' performance on the more difficult self/object displacement task (e.g., Acredolo, 1978; Bremner, 1978).

Although some evidence relevant to this latter issue has appeared in the literature, the findings are equivocal. Bertenthal et al. (1984) reported the results of a study using a paradigm developed by Acredolo (1978) in which an infant anticipates the appearance of a person at one of two windows located to the infant's left and right. One of the windows is surrounded by a series of blinking lights, whereas the other window contains no special cues. In addition, the window with the lights is located on a wall with floor-to-ceiling colored streamers. Infants are initially trained to expect a person to appear at the saliently marked window following the sounding of a buzzer. After training, infants are rotated 180° to the other side of the room and are then tested for whether

they continue to anticipate that the experimenter will appear in the saliently marked window.

The mean age of the infants tested was 32 weeks, but their experience with self-produced locomotion varied. Some of the infants were already creeping, others were still prelocomotor, and a third group was prelocomotor yet had received some experience with independent locomotion through the use of infant walkers. The results from this experiment revealed that both creeping infants and prelocomotor infants using walkers correctly anticipated the appearance of the experimenter following their rotation, whereas the prelocomotor infants began looking toward the plain window following their rotation. These results suggested that prelocomotor infants were using an egocentric frame of reference and disregarding the salient landmark associated with the correct window, whereas locomotor infants were using a landmark-based frame of reference.

In contrast to the results of the preceding experiment, McComas and Field (1984) reported a study using the same paradigm in which locomotor experience did not predict performance. One possible reason for the discrepancy between the two studies is that the latter study did not include a group of prelocomotor infants, but only a group with limited locomotor experience (i.e., 2 weeks). As such, the difference between the two groups of infants was less pronounced, which conceivably contributed to an attenuation in performance differences between the two groups. Although plausible, a complete accounting for the discrepancy between the two studies will require further investigation; thus, it is currently difficult to draw any firm conclusions from this research. An even more important reason for caution in evaluating this research is that the paradigm has come under scrutiny by several investigators because it is claimed that the large number of training trials encourages infants to perseverate in using a self-referent code (e.g., Bremner & Bryant, 1985; McKenzie, Day, & Ihsen, 1984).

#### *Statement of the Problem*

The principal purpose of the current study was to explore further the relation between locomotor experience and object localization following self/object displacement. Locomotor and prelocomotor infants were tested using a paradigm adapted from Bremner (1978) that was designed to minimize the likelihood of teaching infants an

incorrect response. Training trials were kept to a minimum and were structurally different from test trials in order to reduce the chances of response perseveration. The test trials involved hiding an object in one of two containers on a table in front of the infant. After the hiding was completed, either the infant or the table was rotated 180° so that the correct left-right location of the object was reversed relative to the original perspective of the infant.

The opportunity to displace either the hidden object or the infant was another important advantage of this paradigm. It is not clear whether infants will perform differently after either they or the containers are rotated. Bremner (1978) reported better search performance after a rotation of the infant, whereas Goldfield and Dickerson (1981) reported the opposite. Neither experiment controlled for locomotor experience, which might have interacted with the two conditions in somewhat different ways. In order to evaluate this possibility, the current experiment included an assessment of whether locomotor experience affected search performance differentially as a function of whether the infant or containers were rotated.

A final goal was to evaluate whether the relation between locomotor experience and visual tracking reported by Horobin and Acredolo (1986) is specific to a visible displacement task. In their task, no salient landmarks, such as different colored containers, were available to the infant for coding the spatial location of the hidden object. As a consequence, sustained visual tracking may have served as a proxy for coding spatial location. In the current task, visual tracking may not be necessary for coding spatial location because the hiding locations are differentiated by salient cues (i.e., different color containers). If locomotor infants make use of these salient cues for coding spatial location, then they will not necessarily need to track continuously the displaced object to ensure correct localization. By examining the relation between locomotor experience, visual tracking, and search performance in the current experiment, we sought to clarify the relative importance of visual tracking for spatial localization following the onset of locomotion.

#### **Method**

##### *Subjects*

A total of 48 infants (21 females and 27 males) ranging in age from 31 to 34 weeks

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were tested. The mean age was 32.72 weeks (SD = 6.65 days). Seventeen additional infants became fussy and failed to complete the study. Infants were recruited from the birth announcements in the local newspaper and were primarily from white, middle-class families. More systematic data about SES and race were not collected in this study.

### Apparatus

Infants were tested in a square room (2.5 × 2.5 m) formed by four walls constructed of a homogeneous green canvas material. Each infant was tested in the center of the room in a chair that was attached at its base to a round table (diameter = 60.1 cm). The tabletop was painted white and could be rotated around its base and locked in two positions 180° apart. The chair also rotated around the table and locked in two positions 180° apart (see Fig. 1). During the experiment, the experimenter administered all tasks while standing directly across from the infant at the table. A parent stood behind the infant to help ensure that search did not occur until the proper time. The parent remained behind the infant during all phases of the experiment. A video camera was located outside of the room, but it was positioned so that its zoom lens was directed toward the inside through a 3-inch diameter opening in the canvas wall.

Colored cups (height = 12.3 cm and di-

ameter = 9.5 cm at the top) were used to hide objects from infants. During the training phase, a single cup was placed on the table approximately 15.2 cm in front of the seated infant's midline. During the test phase, two cups were aligned horizontally in front of the infant (separated by approximately 15.2 cm); the midpoint between the two cups was 15.2 cm from the infant's midline. Several small, brightly colored toys were available to hide from infants.

### Procedure

*Training phase.*—During this phase, infants were trained to search for a toy hidden in a cup on the table. Training consisted of a progression of three different tasks of increasing difficulty: (1) "uncovered trials" in which a toy was placed in front of the cup on the table so that it was fully visible to the infant, (2) "partially hidden trials" in which a toy was placed partially in the cup such that a part of it was still visible, and (3) "completely hidden trials" in which a toy was placed inside the cup and was no longer visible to the infant. Infants were required to search successfully on two consecutive trials before progressing to the next level of difficulty. If no search occurred on two successive trials, the next trial occurred at the preceding level of task difficulty. An infant was considered trained after successful search on two consecutive completely hidden trials.

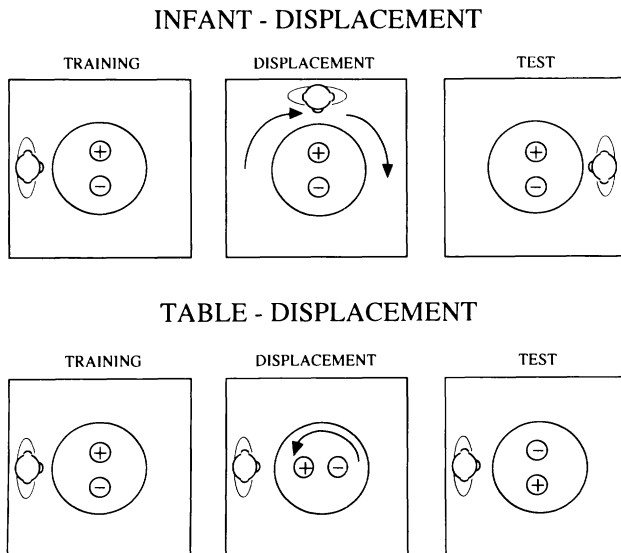


FIG. 1.—Schematic drawing of the test phase of the procedure. Top panel depicts the infant-displacement condition in which the infant is moved around the tabletop. Bottom panel depicts the table-displacement condition in which the tabletop is rotated. Cup containing object is depicted with a "+". Empty cup is depicted with a "-".

The minimum number of trials necessary to reach criterion was six.

Every training trial included the following steps. First, the object was hidden and then the infant was rotated 90° around the tabletop and back to the original position. (Rotation was always in the same direction on training and test trials.) This manipulation was designed to familiarize infants with movements during the test trials so that they would be less likely to become distracted by the change in their position. Infants were permitted to search only after rotation was complete. If the infant was successful in recovering the object, then he or she was encouraged to play with the toy until the next trial began. If the infant did not recover the toy after it had been hidden for 60 sec, then it was uncovered by the experimenter and shown to the infant. After these trials, infants were not permitted to play with the toy. The color of the cup used to hide the object was changed after every trial to ensure that infants would not learn to associate a particular color with the correct hiding place.

*Test phase.*—The test phase began immediately after completion of the training phase. During test trials, two cups of different colors were placed side by side on the table in front of the baby. The toy was hidden in one of the two cups as the infant watched. The test phase consisted of two conditions. In the *infant-displacement* condition, infants were rotated 180° around the table before search was permitted. In the *table-displacement* condition, the tabletop was rotated 180° prior to allowing the infant to search. These conditions are illustrated in Figure 1. A trial ended when the infant searched for a hidden toy or after approximately 1 min if no search occurred. Again, infants who searched successfully were encouraged to play with the toy before the next trial began. Infants who did not search successfully were shown the correct location of the object.

Each infant received five infant-displacement and five table-displacement trials blocked by condition. The color of the cups was changed between every trial, and the toy was hidden consistently on either the left or right side of the infant throughout the session. The presentation order of the two conditions, hiding position (left or right of the infant), and the direction of displacement (clockwise or counterclockwise) were counterbalanced between infants. All sessions were videotaped.

### Scoring

Infants were scored by the experimenter as to whether or not they searched at the correct cup on each trial (0 = incorrect search, 1 = correct search). A second observer who was not present during testing also scored the infants' responses from videotapes ( $n = 45$ ). Agreement between the two coders was very high: 95% on training trials, 97% on infant displacement trials, and 96% on object displacement trials.

The locomotor status of each infant was assessed immediately after the testing session. Each infant was placed on the floor and encouraged to crawl across the room (distance = 3 m) to a parent and an attractive toy. Following the procedure used by Kermonian and Campos (1988), we assigned infants to one of three groups—pre-crawling, crawling, creeping—based on the organization of their prone progression. Twenty infants ( $M = 32.4$  weeks old) were scored as pre-crawling; these babies were unable to reach the other side of the room, and most remained where they had been placed by their parent. Ten ( $M = 33.1$  weeks old) were scored as crawling; their bellies touched the floor as they moved. Eighteen infants ( $M = 32.8$  weeks old) were scored as creeping; they moved on their hands and knees without allowing their bellies to touch the floor. Both creeping and crawling infants reached the other side of the room within 2 min after they had been placed on the floor. A second observer also assessed locomotor status from videotapes of the sessions ( $n = 45$ ). There was 100% agreement between the two observers. Furthermore, parents' reports of their infants' locomotor ability matched those observed.

According to Bertenthal and Campos (1990), the organization of prone progression is a better predictor of performance than is a simple quantitative measure, such as number of weeks since locomotor onset. Nevertheless, the two measures are related. In the current experiment, locomotor experience was considerably greater for creeping than for crawling infants (7.2 vs. 2.7 weeks).

Visual attention during the displacement portion of each trial was coded from the videotapes. Duration of looking at the correct cup, the incorrect cup, the experimenter, and the parent was recorded by two observers. Reliability between the observers was calculated for infant- and table-displacement conditions separately. Correlations and mean absolute differences be-

TABLE 1  
VISUAL ATTENTION: RELIABILITY BETWEEN OBSERVERS

	Correct Cup	Incorrect Cup	Mother	Experimenter
Infant displacement:				
Correlation .....	.83	.90	.99	.91
Mean absolute difference .....	.10	.06	.01	.05
Table displacement:				
Correlation .....	.82	.83	.97	.91
Mean absolute difference .....	.11	.10	.01	.05

tween the two observers' codings are shown in Table 1.

**Results**

There were two principal questions addressed by the data analysis. The first question concerned whether performance differed as a function of locomotor status (precrawling, crawling, or creeping) or displacement type (infant or object). The second question concerned whether visual attention was systematically related to locomotor status and performance. Preliminary analyses revealed no order effects; thus, the data were collapsed across order in the following analyses.

*Search Performance*

On two-choice search tasks, the results from the first test trial are generally considered the most reliable because subsequent responses are confounded by experience from earlier trials (Bremner, 1978). Thus, we begin with a presentation of the results from the first trial broken down by locomotor status and displacement condition. As can be observed in Table 2, four of the six groups showed no difference in the frequency of correct and incorrect responses on the first trial. The only group to show a greater fre-

quency of correct searches than expected by chance was the creeping infants in the infant-displacement condition,  $p < .03$  (binomial test). By contrast, the precrawling infants in the infant-displacement condition showed a greater frequency of incorrect searches than expected by chance,  $p < .01$  (binomial test). This latter response pattern suggested that precrawling infants in the infant-displacement condition were somewhat unique, because they were the only group to consistently use an egocentric frame of reference for coding the location of the hidden object.

These differences in performance as a function of locomotor status and displacement condition were confirmed statistically using log-linear analysis. A hierarchical modeling procedure (Green, 1988) evaluated a model that included main effects for self-movement, object movement, and locomotor status, as well as interactions between locomotor status and infant movement and locomotor status and table movement. Within this model, it was determined that the interaction between locomotor status and the infant-displacement condition was significant,  $F(2,5) = 8.70, p < .05$ . Planned comparisons showed that creeping infants responded correctly more frequently than

TABLE 2  
FREQUENCIES OF CORRECT AND INCORRECT SEARCH FOR THE FIRST TRIAL IN EACH CONDITION

	Correct	Incorrect
Infant displacement:		
Precrawl .....	5	15
Crawl .....	3	7
Creep .....	13	5
Table displacement:		
Precrawl .....	11	9
Crawl .....	3	7
Creep .....	10	8

did the combined group of precrawling and crawling infants in the infant-displacement condition,  $\chi^2 = 6.67, p < .05$ . Also, creeping infants searched successfully more often than did the precrawling group alone in this condition,  $\chi^2 = 6.19, p < .05$ . None of the other main effects or interactions in this model were significant. As such, these results reveal that search performance varied as a function of locomotor status in the infant-displacement condition, but not as a function of locomotor status in the table-displacement condition.

The results based on performance on all five trials were similar, though the frequency of correct responses was somewhat lower. A comparison between performance on the first trial and the mean of the last four trials revealed a significant decline in successful search,  $F(1,36) = 4.29, p < .03$ . As a consequence of this decline across trials, not even the creeping infants in the infant-displacement condition showed above-chance search performance when scores were based on all five trials,  $t(17) = 1.07, N.S.$  By contrast, precrawling infants in this same condition continued to show below chance search performance,  $t(19) = -2.62, p < .02$ .

Although the results from this latter analysis are somewhat confounded by an overall decrement in correct search performance, it is important to emphasize that the general pattern was still consistent with a systematic relation between performance and locomotor status, but only in the infant-displacement condition. Additional evidence for this difference between conditions is provided by the pattern of correlations between locomotor status and performance (based on all five trials). In the infant-displacement condition, the correlation was significant,  $r(43) = .34, p < .02$ ; but this same correlation was not significant in the table-displacement condition,  $r(43) = .21, N.S.$ <sup>1</sup>

#### Visual Attention

In the following analyses, visual attention to the target cup was calculated as the proportion of time during the displacement phase of the trial when the infant was look-

TABLE 3  
MEAN PROPORTIONS OF TIME LOOKING  
AT THE TARGET CUP

	Infant Displacement	Table Displacement
Precrawl .....	.20	.22
Crawl .....	.15	.14
Creep .....	.22	.24

ing at the target cup. Correlations between visual attention to the target cup and performance were significant for both conditions,  $r(43) = .44, p < .01$ ;  $r(43) = .36, p < .02$ , for infant-displacement and table-displacement conditions, respectively. By contrast, correlations between locomotor status and visual attention to the target cup were very low,  $r(43) = .03$ , for the infant-displacement condition, and  $r(43) = -.03$ , for the table-displacement condition. These low correlations were observed because there were no differences in amount of visual tracking displayed by infants in any of the locomotor groups. Mean proportions of looking times for each locomotor group in the two conditions are shown in Table 3.<sup>2</sup>

Contrary to the findings reported by Horobin and Acredolo (1986), the percentage of time that infants engaged in visual tracking of the target cup never approached 100% (which was necessary for scoring an infant as showing sustained visual tracking), and the mean hovered around 20% ( $M = 22\%$ ,  $SD = 20$  in the infant-displacement condition, and  $M = 23\%$ ,  $SD = 22$  in the table-displacement condition). An ANOVA based on all five trials in each condition revealed that there were no differences in the mean proportions of visual tracking of the target cup as a function of locomotor status, displacement condition, or their interaction. Results based on the first trial data were the same.

The preceding findings suggest that locomotor status and visual attention contributed independently to infants' performance. In order to evaluate the relative contribution of each factor, hierarchical regression analy-

<sup>1</sup> The measure based on first trial responses corresponds to a categorical variable and thus cannot be used in a correlational analysis. As a consequence, the preceding correlational analysis as well as subsequent correlational analyses are necessarily restricted to the search performance measure based on all five trials.

<sup>2</sup> Proportions of looking times at the incorrect cup, experimenter, and the mother were not correlated with search performance or locomotor status; thus, these proportions are not discussed further.

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ses were conducted. Visual attention (i.e., proportion of time looking at the target cup) was always entered prior to locomotor status. In the infant-displacement condition, both locomotor status and visual attention to the target cup contributed to infants' search performance,  $F(1,41) = 7.75, p < .05$  and  $F(1,41) = 4.32, p < .05$  for locomotor status and visual attention, respectively. In the table-displacement condition, however, only visual tracking of the target cup contributed significantly to infants' performance,  $F(1,41) = 8.91, p < .05$  (see Fig. 2). Thus, locomotor status contributed significantly to performance in the infant-displacement but not in the table-displacement condition, whereas visual attention to the target cup contributed significantly in both conditions.

### Discussion

The findings from this investigation reveal that locomotor status predicts search performance when infants are displaced relative to a hidden object, but not when a hidden object is displaced relative to the infant.

In addition, correct search performance was systematically related to visual attention, but contrary to previous results and speculations in the literature, there was no evidence of a significant relation between locomotor status and visual attention. Both of these findings will be discussed in turn.

#### Search Performance and Locomotor Status

In the table-displacement condition, infants' search performance was unrelated to locomotor status, whereas search performance in the infant-displacement condition varied systematically with locomotor status. In particular, precrawling infants selected the incorrect container more often than predicted by chance, crawling infants were more variable in their performance, and creeping infants selected the correct container more often than predicted by chance. This pattern was most clearly supported by the analysis of the first trial data. The analysis based on the percentage of trials correct also revealed that precrawling infants selected the wrong container more often than predicted by chance, and that crawling infants were mixed in their performance. Yet,

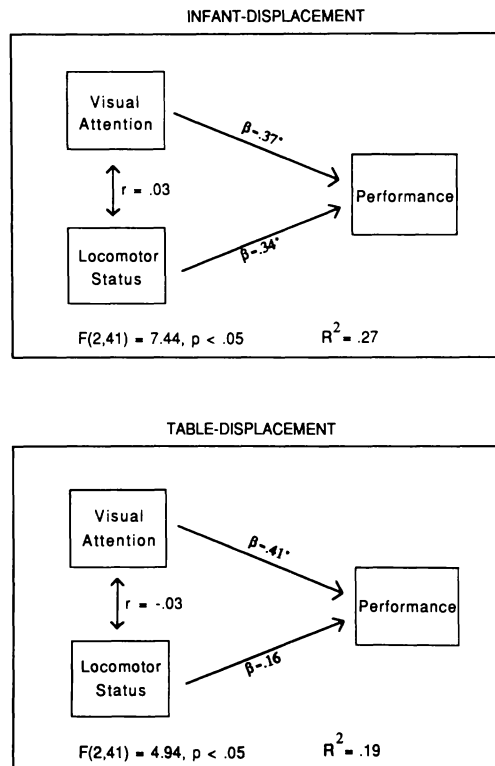


FIG. 2.—Path diagrams illustrate the prediction of performance from visual attention and locomotor status. Top diagram shows the regression model for the infant-displacement condition. Bottom diagram shows the regression model for the table-displacement condition.



evidence suggesting that creeping infants searched the correct container was somewhat attenuated (though clearly in the right direction) relative to the first trial data.

One plausible interpretation for this attenuation in correct responsiveness across trials is suggested by the comparison between performance on the first trial and subsequent trials. The results revealed that search performance was less often correct after the first trial, suggesting that experience on the previous test trials was somehow interfering with performance. It is conceivable that our decision to change the colors of the containers on every trial contributed to the difficulty of the task. This strategy represents a departure from the design of previous experiments (e.g., Bremner, 1978; Goldfield & Dickerson, 1981) in which the color associated with the correct container did not vary across trials. In these previous experiments, infants who were displaced showed a somewhat higher percentage of correct responses than observed in the current experiment. By changing the color of the containers from one trial to the next in this experiment, infants may have become somewhat confused and thus less likely to use the landmark information for localizing the hidden object.<sup>3</sup>

Regardless of whether we consider only the first trial data or the cumulative data, the evidence suggesting an interaction between locomotor status and search performance in the two conditions is fairly robust. Two separate analyses (log-linear and hierarchical regression) revealed an interaction between locomotor status and displacement condition. By contrast, not one analysis revealed a difference in performance as a function of displacement condition *per se*. These findings thus suggest a partial explanation for the apparently contradictory findings reported by Bremner (1978) and Goldfield and Dickerson (1981). Recall that the former experiment reported better performance in the infant-displacement condition, whereas the latter experiment reported the opposite. If a majority of the infants in the Bremner (1978) study began creeping at an early age, while a majority of the infants in the Goldfield and Dickerson (1981) study began creeping at a late age, then we would expect that perfor-

mance in the infant-displacement condition would more often be successful in the former than the latter study. Regrettably, information about the locomotor experience of the infants in these two experiments was not reported, and thus it is difficult to evaluate the accuracy of this interpretation.

Why was locomotor status related to search performance following a displacement of the infant, but not following a displacement of the table? We conjecture that independent mobility necessitates considerable sensitivity to visual and vestibular changes in spatial orientation while moving to a new location (see Bertenthal & Campos, 1990; Bremner & Bryant, 1985). Over time, the infant learns that large-scale changes in spatial orientation (i.e., changes in the network of distances and directions of the infant relative to other objects) are contingent on his or her own movements (Bertenthal, *in press*). As a consequence, locomotor infants are better prepared to anticipate and adaptively respond to large-scale changes following a self-displacement than are prelocomotor infants. Conversely, the table-displacement condition also requires sensitivity to changes in visual information, but these changes are not necessarily associated with self-movement. The movements of the object are produced by other agents and are not generally contingent on the movements of the infant. Thus, there is less reason to expect that infants' experience with their own movements will show a systematic relation to their appreciation of a change in spatial orientation following a displacement of a hidden object. Admittedly, this interpretation is quite speculative, but it is entirely consistent with a context-specific view of development (e.g., Thelen, 1989).

Before concluding this section, it is important to clarify the implications of the reported relation between locomotor status and search performance in the infant-displacement condition. Strictly speaking, these results cannot support a causal connection between locomotor experience and search performance on an infant-displacement task. To do so requires an experimental manipulation of the hypothesized experience (i.e., creeping). Although a few studies (e.g., Kermoian & Campos, 1988) have tried

<sup>3</sup> Another difference between the design of the current experiment and those reporting more frequent localization of the hidden object is that the infants were somewhat younger in this experiment (mean age, 33 weeks vs. 40 weeks). Although age may have contributed to performance differences, we do not consider it a primary factor since performance on the first trial data was as good as the performance reported in the previous experiments.

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to manipulate this experience by providing some infants with artificial locomotor experience through the use of infant walkers, some recent objections to this manipulation have been raised (Bertenthal, in press; Bertenthal & Campos, 1990). First, the experience gained from the use of walkers is at best only an approximation of the experience gained from creeping; thus, a failure to replicate an effect with infants using walkers would be equivocal at best. Second, research ethics dictate that infants cannot be randomly assigned to a group using walkers, especially since use of these devices is questioned by some pediatricians. As a consequence of these reservations, we thought it ill advised to try to pursue this issue by providing an artificial form of locomotor experience to precrawling infants.

In view of the above, it is incumbent upon us to acknowledge the possibility that a relation between locomotor experience and search performance was found because both variables covary with some other unspecified developmental variable. Although rational, it is not at all clear what alternative variable could produce the same pattern of results.<sup>4</sup> Not only is it necessary that this variable predict search performance on an infant- but not on a table-displacement task, but it is also necessary that this variable predict differential performance for precrawling and creeping infants. At least for the moment, parsimony suggests that locomotor experience constitutes the best predictor of search performance in an infant-displacement task.

### *Visual Tracking and Search Performance*

As discussed in the introduction, a common argument is that locomotor experience should lead to improvements in object localization because this experience makes infants more likely to track objects that are undergoing a displacement. Yet, the results from the current study revealed absolutely no relation between locomotor status and visual tracking of the correct container. This finding was somewhat surprising in view of the compelling evidence reported by Horobin and Acredolo (1986). Recall, however, that their study involved a simple visible displacement of the object, whereas the current investigation involved a more complex displacement. More important, the earlier study did not include any salient cues for

coding the location of the hidden object, whereas the current investigation did include salient cues. Conceivably, the absence of salient landmark cues was a contributing factor in inducing infants to use sustained visual tracking for coding location of the hidden object.

In order to evaluate this possibility, we tested an additional nine infants using two identical containers. Contrary to our hypothesis, the results revealed absolutely no increase in visual tracking of the correct container. The mean percentage of visual attention shown to the correct cup was essentially the same as reported in the main experiment.

Clearly, however, there are other differences between the visible displacement task used by Horobin and Acredolo (1986) and the self/object displacement task used in the current experiment. For example, the infant and the containers remained stationary in the visible displacement task, whereas either the infant or the containers changed position in the self/object displacement task. In addition, the former task was conducted in the infant's home, whereas the latter task was conducted in a laboratory. Conceivably, any one of the remaining differences between the two tasks might be responsible for the discrepancies in visual tracking, but currently we can do no more than speculate. Suffice it to say that this difference in visual tracking among locomotor infants provides further evidence for asserting that visible and self/object displacement tasks are structurally different.

Although visual tracking was not related to locomotor status in the current experiment, it was related to search performance. In fact, visual tracking predicted performance in both conditions. This finding is consistent with the general consensus in the literature that search performance improves as a function of visual attention (e.g., Acredolo, Adams, & Goodwyn, 1984; Bremner, 1978); but note that the relation asymptotes long before visual attention is present 100% of the time (which by definition is necessary for sustained visual tracking). Apparently, infants must look sufficiently long enough to encode the relevant information (e.g., color of the correct cup), but it is not necessary for them to track the

<sup>4</sup> The most obvious possibility is that both variables correlated with age, but the correlations between age and performance were quite low,  $r(43) = .03$ ,  $r(43) = .02$  for infant-displacement and table-displacement conditions, respectively.

correct location continuously, as suggested by Horobin and Acredolo (1986). Creeping infants are clearly able to use some of the other information available to them to localize a hidden object following a displacement of their own position relative to that of the hiding cups. Included in the information available to them is the color of the correct container and visual and vestibular information suggesting that their spatial orientation relative to the cups is changing. Conceivably, creeping infants use all of this information in choosing the correct cup. Interestingly, some of this information (e.g., vestibular stimulation, perspective changes in the spatial layout, etc.) is not available when the cups are displaced, which suggests an additional reason why infants perform better in the infant-displacement task than in the table-displacement task (see Bremner & Bryant, 1985).

In sum, the findings from this investigation extend those from previous studies suggesting a relation between locomotor experience and search for displaced objects. Consistent with previous studies using a visible displacement task, this study revealed a systematic relation between locomotor status and performance. Yet this relation was restricted to infant displacements and did not generalize to displacements of the containers. In addition, this relation was clearly not mediated by increased visual tracking even though this variable was related to the performance of locomotor infants in the visible displacement task. It is thus clear that the effects of locomotor experience on infants' performance are quite specific, and we must therefore apply considerable caution in generalizing results from one task to another.

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