Locomotor Experience Influences the Spatial Cognitive Development of Infants with Spina Bifida

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Abstract

This study tested the hypothesis, derived from studies of normal infants, that experience with self-produced locomotion facilitates the development of two important spatial cognitive skills: a two-position object permanence manual search task, and a task assessing the infant's following of the point/gaze gesture of the experimenter. Both of these tasks, as assessed in these studies, show median ages of onset between 7 and 9 months in normal infants, but very recent studies with normals have shown that, within this age group, locomotor experience, rather than age, forecasts the development of these skills. The specific question tested in this study concerned whether infants who were delayed in locomotor development due to meningomyelocele were also delayed in spatial skills until after the age at which locomotion was attained. The hypothesis was confirmed with both tasks.

Locomotor experience may be an unexpectedly powerful process underlying specific developmental transitions (Campos Anderson, Barbu-Roth, Hubbard, Witherinton, & Hertenstein., 2000). In this report of a group of motorically-delayed infants, we study how such locomotor experience is related to the development of two spatial cognitive skills – object permanence, and referential gestural comprehension.

Clinicians have noted the presence of spatial cognitive deficits in patients with motor impairments, and have speculated on the potential efficacy of motoric interventions such as crawligators and powered mobility devices as therapeutic interventions (Campos, Svejda, Campos, & Bertenthal, 1982; Shaffer, Wolfe, Friedrich, Shurtleff, Shurtleff, & Fay, 1986). Recent studies of normal infants are confirming the clinicians' intuitions about a link between locomotor experience and a variety of cognitive, as well as emotional, social, and perceptual processes (Bertenthal, Campos, & Barrett, 1984; Campos et al, 2000). Indeed, many phenomena ordinarily thought to develop principally as a function of age in fact may have a closer relation to the infant’s locomotor experience.

The development of object permanence is one such example. This task – the search for an object hidden under one of two cloths – has a median age of onset at 7 months (Uzgiris & Hunt, 1975, at a time prior to the “Back to Sleep” campaign that resulted in one-month delays in crawling acquisition), but it does not typically develop at that age if the infant lacks locomotor experience. In an early study, eight-month-olds who were prelocomotor searched correctly for the hidden object on only 22% of trials, whereas locomotor infants of the same age did so on 72% of the trials (Campos & Bertenthal, 1990). Further evidence of the importance of locomotor experience comes from studies of eight-month-old prelocomotor infants with walker experience, who perform like locomotor infants, solving the task on 67% of trials (Kermoian & Campos, 1988).

Referential gestural comprehension also is more closely related to locomotor experience than to age. Referential gestural comprehension shows a developmental progression from looking principally at the gesturing person, to looking in the general direction of the gaze or point, to looking with increasing precision at the specific target (Morissette, Ricard, & Decarie, 1995). The infant's tendency to look in the direction of the gaze, rather than at the gesturing person, develops normatively, with the task described in this report, at about 8 months (Kermoian, Zumbahlen, & Coletti, 1991). However, prelocomotors do not show this trend. At 8.5 months of age, they are as likely to look at the examiner as at the target. Same-aged locomotors and prelocomotors with walker experience, by contrast, are twice as likely to look in the direction of the gesture as at the examiner (Kermoian, Campos, & Chen, 1992). Thus, within the limits of the ages studied, locomotor experience appears to have a significant impact on both object permanence and joint attentional skills.

These recent studies are theoretically important for a variety of reasons. First, both object permanence and referential comprehension are skills that underlie many other important cognitive changes. Object permanence is thought to be a component process in concept formation, aspects of language acquisition, representation of absent entities, the development of attachment, and possibly a number of other emotional changes (Haith & Campos, 1977). Referential gestural comprehension is critical for the infant to become a communicative partner, i.e., for language learning, the transmission of emotional information to the baby, and understanding the intentions of another (secondary intersubjectivity) (Trevarthen & Hubley, 1978).

These findings also challenge orthodox conceptualizations of the processes underlying developmental changes in infancy (Hamburger, 1964). Both of these spatial cognitive skills have been explained entirely in maturational terms. In the case of object permanence, a specific neurological site – the dorsolateral prefrontal cortex – has been hypothesized as a necessary maturational precursor to successful manual search (Diamond, 1990; Kagan, Kearsley, & Zelazo, 1978). By contrast, Piaget (1952) and others (Hebb, 1949; Zaphorozhets, 1973) proposed that these developmental changes are brought about by motoric experiences and active exploration of the world.

Findings linking locomotor experience and psychological development have implications for understanding the cognitive development of infants with locomotor delays. If locomotor experience is indeed a precursor of improved object permanence and joint attention performance, then infants who are delayed in the onset of locomotion should show spatial cognitive deficits for the period of the delay, and a spurt in these skills following the delayed onset of locomotion. In this report, we test this hypothesis by tracing monthly the development of crawling experience, the acquisition of manual search for hidden objects, and the ability to follow the point and gaze in infants with meningomyelocele. We expected that locomotor experience would precede improvement in performance in each of these tasks.

Method

Participants

The study included seven infants who were motorically delayed because of meningomyelocele. The individual participants began self-produced locomotion three months later than typically developing infants tested at the same time in our lab. The ages were as follows: P-1 10.5 months; P-2 11.5 months; P-3 10.5 months; P-4 8.5 months; P-5 10.5 months; P-6 13.5 months; P-7 10.5 months. Locomotion was defined as intentional prone progression (combat crawl) of four feet within two minutes.

Sample infants were recruited from the Birth Defects Clinic of the Children's Hospital

Medical Center in Seattle if they met the following criteria as assessed by clinical evaluations: (1) diagnosis of meningomyelocele, (2) six months of age or older and prelocomotor, (3) lesion level L4-5 or below, (4) controlled hydrocephalus with shunts placed within the first two weeks of life, (5) absence of spasticity in their upper limbs, (6) no evidence of other major disabilities, anoxic encephalopathy, or central nervous system syndromes. Data on two additional subjects were excluded from analysis, one due to recurrent illness and one because of the development of upper limb spasticity. The parents of all infants provided written informed consent prior to their infant's participation in the study.

Procedure

Infants were tested once a month beginning at the age of entry into the study, until two months following the onset of self-produced locomotion. Data presented in this paper were collected during the assessments taken two months immediately prior to and two months immediately following locomotor onset.

During each test session infants were individually administered two tasks tapping different spatial cognitive skills. One was an object permanence, manual search task and one was a test of following another person's point and gaze gestures. At nine months of age, the infants also were given a recognition memory task devised by Fagan (Fagan & Singer, 1983), to determine whether their cognitive functioning was within the normal range. This test has been shown to predict IQ at four and seven years of age from an assessment taken in middle infancy (Bornstein & Sigman, 1986) and was selected for this study in preference to one of the traditional tests of infant mental development because it yields a score based on visual responding and therefore is not confounded by motoric delays or difficulties. All tasks were videotaped.

Object permanence Task. The manual search task used in this study was a variant of Piaget's (1954) Stage 4 two-position hiding task in which a target object is hidden under one of two perceptually distinct locations. For this task, the infant was seated in a high chair which had foam rubber inserted to provide trunk support and allow the infant uninhibited use of the upper extremities. During the session, the examiner knelt on the floor facing the baby and the mother stood behind the infant's chair.

A tray with two hiding wells, the closest edges of which were located 20 cm apart, was placed directly in front of the infant, between the infant and examiner. During test trials, the hiding wells were covered by perceptually distinct cloths, one black and one white. Several small toys were used as target objects.

After the infant briefly manipulated the target toy, the examiner administered warm-up trials in which a toy was partially hidden under a single cloth. During the warm-up trials, neither hiding well was visible. After the infant had successfully retrieved the toy on two successive warm-up trials, three test trials were administered. For each test trial, the examiner hid the toy in one of the two wells, and then covered both wells simultaneously. The well selected for hiding was randomly determined prior to each test session, but remained the same throughout a given session.

In order to pass the test on a given month, the infant needed to uncover and retrieve the object without looking toward the empty hiding well on two of three trials. Scores for the two tests immediately prior to locomotion were then averaged into a single pre-locomotion score, and those from the two tests immediately following locomotion were averaged into a single locomotion score. Three scores were possible: 0 (failed the test both months), 1 (passed a test on one month but not the other), and 2 (passed the test on both months). The two infants in the sample who had only one test prior to crawling were assigned a score for the missing test session based on a single pre-locomotion session, given that there was no significant difference between the two pre-locomotion scores for infants who had been administered two tests. Two coders, both blind to the locomotor status of the infants, independently scored the videotapes. Inter observer reliability based on all tests was significant (Kappa = .82, Z = 4.79, $p < .001$).

Following the Point and Gaze. To test the infant's ability to follow the point and gaze gesture of another, the infant was seated on the mother's lap in a 1.53 m square cubicle with dark walls. The examiner knelt on the floor .5 m in front of the infant. Targets, eight in all, were located on the walls 45 degrees above and below the infant's eye level, and 45 degrees and 90 degrees to the infant's left and right. The targets were brightly colored stuffed animals whose position was randomly determined for each session. A camera was located behind the curtains, with the lens positioned slightly above and to the right of the examiner's shoulder.

After establishing eye contact with the infant, the examiner said the infant's name and pointed with an across-the-body point and gaze gesture to the appropriate target while simultaneously saying, "(Baby's name). Look at the toy!" The examiner then held the gesture for three seconds. For each test session the examiner pointed and gazed at a predetermined random set of four of the eight targets, four times each, for a total of 16 trials.

The first three seconds of each trial following the last word in the examiner's utterance were scored for the direction of the infant's gaze. Three scores were then calculated: (1) the proportion of trials in each session in which the infant looked solely at the examiner's face or pointing finger, (2) the proportion of trials in which the infant's first shift in gaze away from the examiner was directed toward one of the targets on the wall toward which the examiner was pointing, and (3) the proportion of trials in which the infant's first shift in gaze away from the examiner was directed toward one of the targets on the wall opposite that to which the examiner was pointing. All videotapes were scored by two coders who were blind to the locomotor status of the infant and to the location to which the examiner was pointing. Interobserver reliability, for all 26 sessions, calculated by the Pearson product-moment correlation for each of the three measures of direction of infant gaze, was above 0.99.

The three measures of direction of infant gaze from the two sessions prior to locomotion were averaged separately into a pre-locomotion score for each measure. The same measures were then averaged for the two sessions following the onset of locomotion. A score of 100 demonstrates that the infant looked at a given location 100 percent of the trials, a score of 0 demonstrates that the infant looked at a given location 0 percent of the trials. The two infants in the sample who had only one test prior to crawling were assigned scores based on a single pre-locomotion session, given that there was no significant difference between the two pre-locomotion scores for those infants who had received two tests.

Recognition Memory Task. The Fagan Test of Recognition Memory (Fagan & Singer, 1983) was administered and scored by an examiner who was highly experienced with the task, and who maintained reliability throughout the study with one of the developers of the task. Each infant received a single score reflecting the percentage of time spent looking at a novel versus a familiar photograph averaged across a total of 10 trials. One infant, who was too old at entry into the study to be tested on this task, was instead administered a Bayley MDI by clinic staff at 19 months of age.

Results

Object permanence Manual Search Task

The onset of locomotion resulted in a marked improvement in search for an object hidden in one of two locations. Prior to crawling, infants passed only 14.29 percent (SD = 37.80) of the tests, as compared to 64.29 percent (SD = 26.73) of tests following locomotion (Wilcoxon Matched-pairs

Signed-ranks Test, Z = 1.78, $p < .05$, one-tailed). These data are presented in Figure 1. Figure 2 presents the data from each of the seven participants individually and shows the improvement in object permanence following the onset of locomotion in five of the seven infants. This improvement in performance following locomotion was especially notable for participant number 6 who did not pass any tests until the relatively late onset of locomotion at 13.5 months.

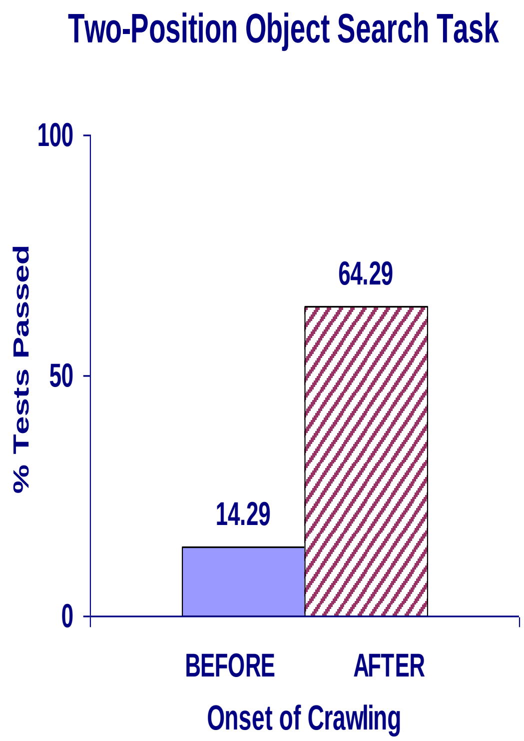

Figure 1

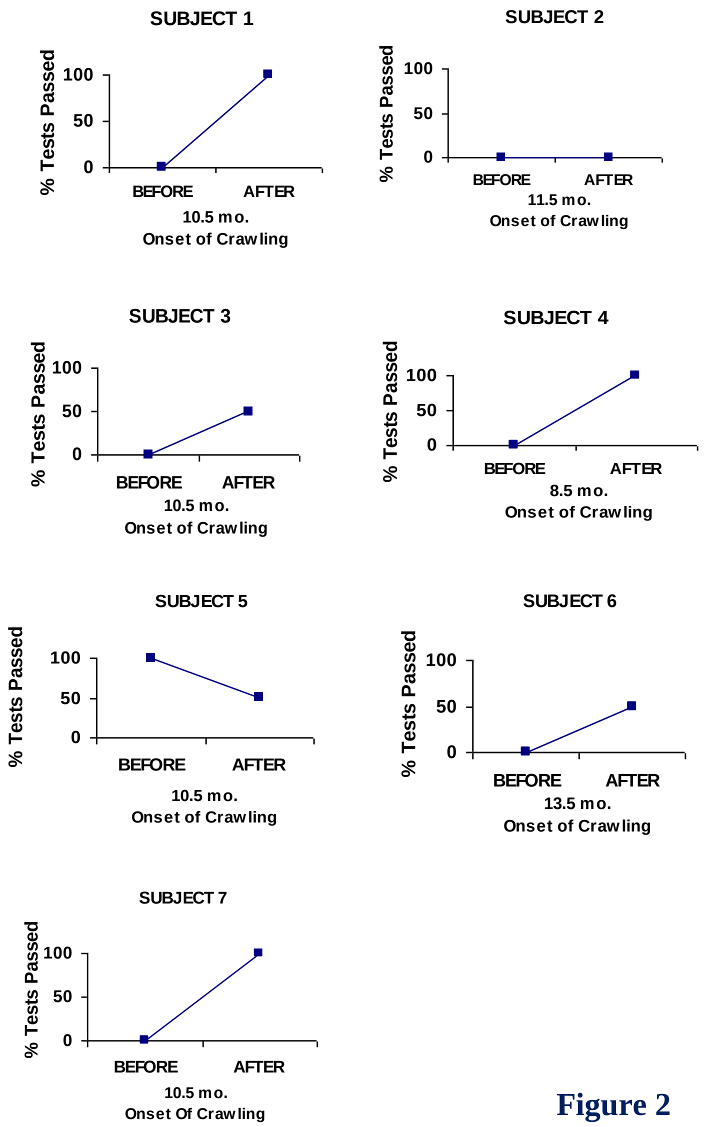

Figure 2

Figure 1 and 2:

Percentage of manual search tests passed prior to and following the onset of locomotion averaged across infants, and also for each infant. The age of crawling onset is indicated below the arrow.

Following the Gaze and Point

In the tests following locomotion, there was a striking shift away from focusing on the examiner's face or finger during the gaze/point gesture to looking in the general direction of the gesture. Prior to crawling, infants looked solely at the examiner's face or finger on 79 percent (SD = 10.43) of the trials, as compared to 45 percent (SD = 25.31) of the trials following locomotor onset (Wilcoxon Matched-pairs Signed-ranks Test, Z = 2 .20, $p < .05$). Following the onset of locomotion, infants were not only more likely to look away from the examiner but were also more likely to look in the general direction of the examiner's gesture (i.e., at one of the four targets on the wall toward which the examiner was pointing). Looking toward one of these four targets significantly increased from 12.50 percent (SD = 5.98) prior to locomotion to 50.45 percent (SD = 25.86) following locomotion (Wilcoxon Matched-pairs Signed-ranks Test, Z = 2.20, $p < .05$, one-tailed).

To ensure that the increase in looking in the direction of the examiner's point/gaze gesture following the onset of locomotion was not merely a result of a generalized increase in responding, we examined changes in looking at targets on the wall opposite that toward which the examiner was pointing. The percentage of looking toward targets on this wall was low in both the pre-locomotion and locomotion tests, 9 (SD = 10.27) and 3 (SD = 5.40) percent respectively, and did not change significantly with the onset of locomotion. Locomotor experience thus facilitated search in the direction of the examiner's gaze/point gesture without increasing the tendency to look to non-referenced locations.

Figure 3 and Figure 4 present the mean data for this study, and Figure 5 presents the data from the individual participants for two measures: looking solely at the examiner, and looking at one of the four targets on the wall toward which the examiner gestured.

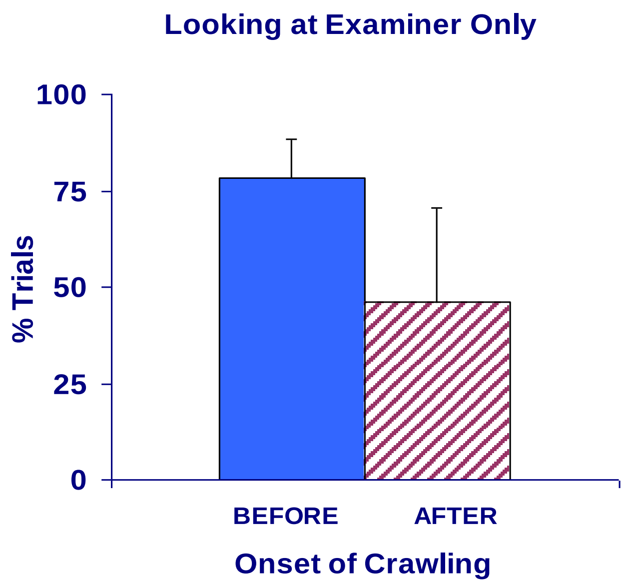

Figure 3

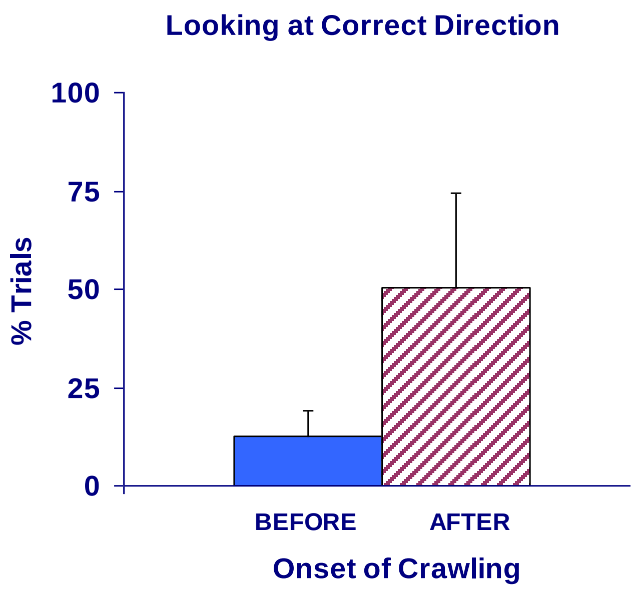

Figure 4

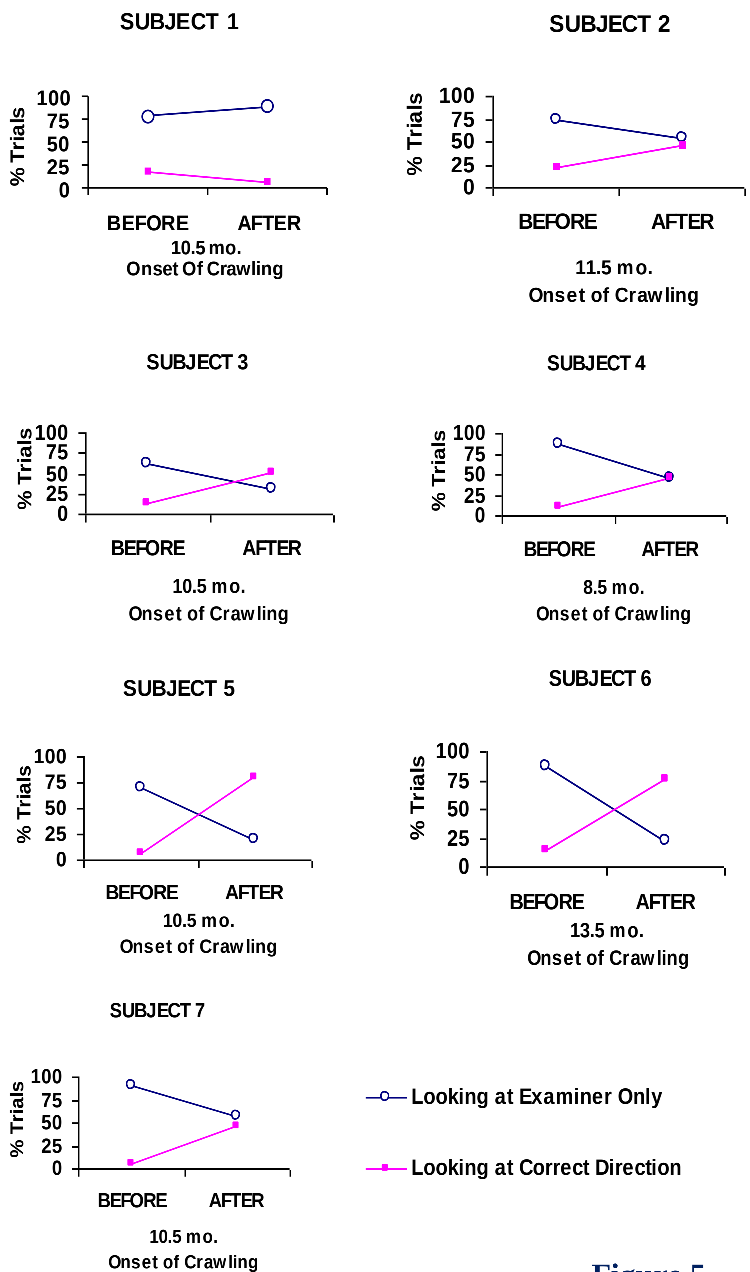

Figure 5

Figure 3, 4 and 5:

Percentage of trials looking solely to the experimenter and percentage of trials looking to targets on the correct wall prior to and following the onset of locomotion averaged across participants, as well as for each infant. The age of crawling onset is indicated below the arrow.

Six of the seven participants began to look less at the examiner and more at the correct side within two months after the onset of locomotion, again regardless of the age when combat crawling began. It should be noted that the single infant who showed precocious performance on this task was not the same infant who showed similar precocity on the object permanence task.

Taken together, these findings suggest that following the gaze/point gesture of another increases dramatically after infants begin to move independently, and is not merely a function of an overall increase in response rate.

Recognition Memory Task

The findings from the test of recognition memory showed that infants in this study were performing within the normal range. The scores did not statistically differ from norms gathered for normal infants. The mean score of the six infants in this study was 56 (SD = 8.96), as compared to a mean of 60 (SD = 5.99) found for normal infants of the same age. (The mean scores for the four subjects tested at 9 and 12 months and who were prelocomotor at the 9 month and postlocomotor at the 12 month exam were 54.42 and 53.90 respectively.) The one infant who entered this study beyond the age at which we could administer the recognition memory test was given a Bayley MDI at 19 months and received a score of 96, also within the normal range. Thus, the delays in performance on spatial cognitive tasks in prelocomotor infants with meningomyelocele could not be attributed to delays in more generalized cognitive functions such as those tapped by the Fagan or the Bayley tests.

Discussion

The results of this study document the importance of locomotor experience for spatial cognitive development. In almost all of the infants, performance on the object permanence and the referential gestural communication task (following the point/gaze gesture of another) was poor until the infant became locomotor. Moreover, the spurt in psychological performance was independent of the age when locomotion was attained. A particularly surprising finding was the consistency of improvement in performance following the acquisition of locomotion, despite the pervasive disabilities associated with myelodysplasias. We conclude that locomotor experience has at least a facilitatory role in the development of certain cognitive skills, particularly spatial ones.

A number of processes may be implicated in the link between locomotor and psychological development. One factor is ecological. Locomotion may sharply increase the number of instances of occlusion and reappearance of objects as the infant moves about and alternately encounters and overcomes obstacles to vision. Moreover, infants have a reason for remembering the locations of previously encountered objects when they can move from place to place. These experiences may sensitize the infant to develop new skills of recovering hidden objects. Similar1y, locomotion may result in marked increases in distal vocal communications from the mother directed at the newly-mobile infant (e.g., limit setting, comments on what the infant is doing, etc.) (Campos, Kermoian, & Zumbahlen, 1992). These distal communications may prod the infant to link the mother's vocalization, gaze orientation, and pointing gesture to an environmental referent.

A second factor is a shift in spatial coding processes (Acredolo, 1990). Piaget (1954) speculated that infants undergo a major developmental shift in the second half year of life. This shift involves a change from an egocentric coding strategy (i.e., a strategy whereby objects are located by reference to one's own body) to an allocentric coding strategy (i.e., a strategy whereby objects are located by reference to other objects or events in the environment, as opposed to one's body). Self-produced locomotion may facilitate such a shift by rendering ineffective a body-centered coding strategy (Campos et al., 2000). For instance, an object that at one time is reliably remembered as being located on one's right or one's left will no longer be retrieved once a crawling-induced shift in body position changes the infant's relation to the object. A new coding strategy is now needed that involves relating two objects separated in space to each other. Such a coding strategy permits the infant to relate two environmental objects, such as the examiner's finger and referential target in the point/gaze task, or to identify correctly which of two spatially-disparate and perceptually-distinct cloths signals the location of the single hidden object in the object permanence task.

A third factor is attentional. Self-produced locomotion, in a fashion analogous to an adult driving a car, requires investment of attention to cues in the environment relevant to goal attainment. Such attention may generalize to other tasks and may then become a strategy in solving problems or attaining goals even when the subjects are not locomoting (as is the case in the two tasks used in this study). Consistent with this interpretation, attentional deployment appeared to change once infants became mobile. For instance, during the delay between hiding and search in the object permanence task, the post-locomotor handicapped infant appeared to be less distractible, more task-oriented, and more likely to align their head, eyes, and bodies toward the hiding location than they were before they became locomotor. This change toward decreased distractibility following locomotion onset has been found in normal infants in many other studies of object permanence as well as in studies of following the point/gaze (Campos, Bertenthal, & Kermoian, 1992; Kermoian, Campos, & Chen, 1992; Topal, Gergely, Miklosi, Erdohegyi, & Csibra, 2008).

These three processes – shift in ecological factors, changes in spatial coding strategies, and increased attentiveness – do not exhaust possible explanations of improved object permanence performance and comprehension of referential gestural communication. It is also likely that the processes work in concert, interacting to bring about the developmental shifts we have observed.

The present study suggests that locomotor experience may be sufficient to produce developmental changes, and to do so in the great majority of infants. These findings are inconsistent with the conclusions of Decarie and Kopp that locomotion is unimportant for spatial cognitive development (Decarie, 1969; Kopp & Shaperman, 1973). It may be that their failure to obtain positive findings was due to the use of orthotics by many of the participants in their studies.

The present study also suggests that locomotor experience may not be necessary to produce such developmental change. The ecological, attentional, and spatial coding skills that we propose as mediators of the developmental changes may be available to, but not ordinarily utilized by, the prelocomotor infant. To the extent that these processes can be recruited in the prelocomotor infant by factors other than locomotion, we would expect a prelocomotor infant to perform comparably to a locomotor one. The operation of such alternative developmental pathways may explain why some prelocomotor infants perform similar1y to the typical locomotor baby. Nevertheless, locomotion clear1y appears to be the most effective means of producing the developmental shifts in spatial cognition that we have studied.

One of the most exciting implications of this research project is that experience associated with locomotion may help organize the structures in the brain known to control performance of spatial cognitive tasks – that is behavioral functions may help bring about neurophysiologic restructuring. The recent research by Bell on frontal EEG changes that follow the acquisition of locomotion is entirely consistent with this implication (Bell & Fox, 1988). If further support is obtained for a link between locomotor experience and brain reorganization, we will confirm with humans the position of Gottlieb (1991), Jenkins (1990), and Greenough and Black (1986) on the functional consequences of specific environmental experiences for brain development in birds, rodents, and monkeys.

These lines of research suggest new directions for the investigation of linkages between motor development and developmental transitions more generally. Historically, motor behavior has been used as an end-in-itself – a maturational marker of development. However, visual scanning, reaching, crawling, walking, running, and speech may, each in its own way, be linked to important new developmental acquisitions (Campos, 2006). In addition, motor factors have unsuspected ongoing developmental significance. Once acquired, motoric patterns persist, and by doing so, may help maintain the skills that they facilitated in the first place. This is a hypothesis that, to our knowledge, has not been tested.

References:

Acredolo L. P. (1990). Behavioral approaches to spatial orientation in infancy. In A. Diamond (Ed.), *The development and neural bases of higher cognitive function* (pp 596-612). New York: The New York Academy of Sciences.

Bell M. A., & Fox N. A. (1988). Developmental changes in the EEG from 7 to 12 months of age. *Psychophysiology*, *25*, 434.

Bertenthal B. I., & Campos J. J. (1990). A systems approach to the organizing effects of self-produced locomotion during infancy. In C. Rovee-Collier & L. Lipsitt (Eds.), *Advances in infancy research* (pp. 2-60). Hillsdale, NJ: Erlbaum.

Bertenthal B. I., Campos J. J., & Barrett K. C. (1984). Self-produced locomotion: an organizer of emotional, cognitive, and social development in infancy. In R. N. Emde & R. J. Harmon (Eds.), *Continuity and discontinuities in development* (pp. 175-209). New York: Plenum.

Bornstein, M., & Sigman, M. (1986). Continuity in mental development from infancy. *Child Development, 57,* 251-274.

Campos, J. (2006, June). *Epigenetic processes in infant development.* Presidential Address presented at the 14th Biennial Meetings of the International Society for Infant Studies, Kyoto, Japan.

Campos, J. J., Anderson, D. I., Barbu-Roth, M. A., Hubbard, E., Witherington, D. C., & Hertenstein, M. (2000). Travel broadens the mind, *Infancy, 1,* 149-219.

Campos J. J., & Bertenthal B. I. (1990). Locomotion and psychological development in infancy. In F. Morrison, K. Lord, & D. Keating (Eds.), *Applied developmental psychology: Psychological development in infancy* (pp. 229-258). New York: Academic Press.

Campos J. J., Bertenthal B. I., & Kermoian R. (1992). Early experience and emotional development: the emergence of wariness of heights. *Psychological Science, 3*, 61-64.

Campos J. J., Kermoian R., & Zumbahlen M. R. (1992). Socioemotional transformations in the family system following infant crawling onset. In N. Eisenberg, & N. A. Faber (Eds.), *New directions for child development* (pp. 25-40). San Francisco: Jossey-Bass.

Campos J. J., Svejda M., Campos R. G., & Bertenthal B. I. (1982). The emergence of self-produced locomotion: Its importance for psychological development in infancy. In: D. O. Bricker (Ed.), *Intervention with at-risk and handicapped infants: From research to application* (pp. 195-216). Baltimore: University Park Press.

Decarie T. (1969). A study of the mental and emotional development of the thalidomide child. In B. Foss (Ed.), *Determinants of infant behavior* (Vol. 4, pp 167-188). London: Methven & Co. Ltd.

Fagan J. F., & Singer L. T. (1983). Infant recognition memory as a measure of intelligence. In L P. Lipsett (Ed.), *Advances in Infant Research* (pp. 31-78). Norwood, NJ: Ablix.

Diamond, A. (1990). The development and neural bases of memory functioning as indexed by the AB and delayed response tasks in human infants and infant monkeys. *Annals of the New York Academy of Sciences, 608*, 263-317.

Gottlieb G. (1991). Experiential canalization of behavioral development: theory. *Developmental Psychology*, *27*, 4-13.

Greenough W., Black J., & Wallace C. (1986). Experience and Brain Development. *Child Development*, *58*, 539-559.

Haith M., & Campos J. J. (1977). Human Infancy. *Annual Review of Psychology*, *28*, 252-293.

Hamburger V. (1964). Ontogeny of behaviour and its structural basis. In D. Richter (Ed.) *Comparative Neurochemistry: 5th International Neurochemistry Symposium* (pp. 21-24). Oxford, New York: Pergamon Press.

Hebb, D. O. (1949). *Organization of Behavior*. New York: Wiley.

Jenkins W. M., Merzenich M. M., Ochs M. T., Allard T., & Guic-Robles E. (1990). Functional reorganization of primary somatosensory cortex in adult owl monkeys after behaviorally controlled tactile stimulation. *Journal of Neurophysiology*, *63,* 82-104.

Kagan J., Kearsley R. B., & Zelazo P. R. (1978). *Infancy: Its place in human development*. Cambridge, MA: Harvard University Press.

Kermoian R., & Campos J. J. (1988). Locomotor experience: A facilitator of spatial cognitive development. *Child Development*, *59*, 908-17.

Kermoian R., Campos J. J., & Chen H. (1992, May). *Self-produced locomotor experience facilitates the following of referential gestural communication: An ecological approach to the study of developmental transitions*. Symposium, Eighth International Conference on Infant Studies, Miami, FL.

Kermoian R., Zumbahlen M., & Coletti E. (1991, April). *Referential gestural communication: Developmental course and underlying process*. Paper presented at the meeting of the Society for Research in Child Development, Seattle, WA.

Kopp, C. S., & Shaperman J. (1973). Cognitive development in the absence of object manipulation during infancy. *Developmental Psychology*, *9*, 430.

Morissette, P., Ricard, M., & Decarie, T. G. (1995). Joint visual attention and pointing in infancy: A longitudinal study of comprehension. *British Journal of Developmental Psychology*, *13*, 163-175.

Piaget J. (1952). *The Origins of Intelligence in Children*. New York: International University Press.

Piaget J. (1954). *The construction of reality in the child*. New York: Basic Books.

Shaffer J., Wolfe L., Friedrich W., Shurtleff H., Shurtleff, D., & Fay G. (1986). Developmental Expectations: Intelligence and Fine Motor Skills. In D. B. Shurtleff, (Ed.), *Myelodysplasias and Extrophies: significance, prevention, and treatment* (pp. 359-72). Orlando: Grune &

Stratton.

Topal, J., Gergely, G., Miklosi, A., Erdohegyi, A., & Csibra, G. (2008). Infants' perseverative search errors are induced by pragmatic misinterpretation. Science, 321, 1831-1834.

Trevarthen C., & Hubley P. (1978). *Secondary intersubjectivity: Confidence, confiding and acts of meaning in the first year*. London: Oxford Press.

Uzgiris I., & Hunt J. McV. (1975). *Assessment in Infancy: Ordinal Scales of Psychological Development*. Urbana, IL: University of Illinois Press.

Zaporozhets A. V. (1973). The development of perception and activity. *Early Child Development and Care*, *2*, 49-56.

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