Ecological Approaches to Cognition
Essays in Honor of Ulric Neisser

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Obstacles to Understanding:
An Ecological Approach to Infant Problem Solving

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THE PROBLEM OF MOBILITY

This chapter focuses on a very basic and practical kind of problem solving—safely navigating the ground ahead. The problem of mobility is manifold. From their first crawling or walking steps, infants must find their way amidst myriad threats to balance control. The ground is covered with a variety of surfaces—slippery linoleum, deformable playpen mattresses, sloping driveways, and household stairs. Paths are cluttered with furniture, toys, and other obstacles. Interesting places to visit lurk around the corner or behind a door. All the while, infants’ own bodies and skills are continually changing. Infants’ top-heavy proportions gradually slim down, and the ratio of muscle mass to fat increases. Infants’ proficiency at locomotion changes from week to week as babies master belly crawling, progress to hands and knees, cruise sideways along furniture, and finally walk upright.

Solving the problem of mobility in a real world environment is a continual decision process. Figuring out where to go and how to get there requires coordination of skills across a number of psychological domains and time scales: coping with the sheer biomechanics of moving the limbs in a gravitational field, contending with different ground surfaces and their effects on balance control, gathering perceptual information about the ground ahead and about infants’ own propensities, searching out alternative means to traverse a surface or reach a location, and so on.
Moreover, human mobility is not a solitary enterprise. Problem solving is normally a joint endeavor. Typically, infants’ first steps are into the waiting arms of an encouraging caregiver. Parents give a warning shout and rush to the rescue when babies decide to climb out of their cribs or tackle the household stairs. Parents physically structure infants’ environment by gating stairs and removing dangerous obstacles. They decide whether babies are held, restrained in a high chair or playpen, or allowed to roam around on the floor. Reciprocally, infants can request help when they get stuck under the kitchen table or thwarted by a closed door. Infants can glance at caregivers’ faces for clues about what to do in potentially risky or ambiguous situations (e.g., Sorce, Emde, Campos, & Klinnert, 1985).

OBSTACLES TO UNDERSTANDING

Traditionally, research on infant locomotion has focused on normative descriptions of the ages and stages of motor milestones. Pioneering investigators in the 1930s and 1940s provided the first qualitative descriptions of changes in infants’ gait. Each stage-like transition marked a small developmental milestone toward erect locomotion. Gesell and Ames (1940), for example, identified 22 ministages in the development of crawling, from worm-like forward movements with the belly on the floor to more erect crawling on hands and knees or hands and feet. McGraw (1945) and Shirley (1951) described seven stages in the development of walking, beginning with newborn reflexive stepping movements to intentional walking toward the end of infants’ first year.

Historically, the early pioneers may have done their jobs too well. The prevailing focus on normative stage-like changes in gait led psychologists to consider locomotor development as a series of isolated biomechanical events. Typically, child development textbooks and infant assessment scales represent locomotor development with a catalog of infant reflexes and a series of line drawings in a milestone chart. Divorced from its context in a complex environment of surfaces, places, and people, infant locomotion appears separate from skills in perceptual, cognitive, and social domains.

Moreover, for the past 50 years, researchers explained infants’ progress through the requisite locomotor stages as the result of neuromuscular maturation. Progress from one stage of prone progression to the next resulted from fluctuations in muscle strength, endogenous changes in body dimensions, and maturation of the neural substrate (Gesell & Ames, 1940). Similarly, infants’ eventual triumph over gravity in upright positions reflected growth changes and increasing myelination of the corticospinal tract (McGraw, 1945). In fact, clinicians typically assess infants’ brain de-

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velopment by observing changes from more obligatory, reflexive movements to more flexible, intentional control of limb movements.

NEW ROUTES TO UNDERSTANDING

Our aim in this chapter is to provide an illustration of how infant locomotion can be rescued from the isolated pages of a textbook milestone chart and resituated in the rich world of everyday mobility. We focus on identifying and understanding connections across different domains of infant development—physical maturation, changes in exploratory activity, advances in attention and perceptual differentiation, emerging cognitive abilities, and the social context of infant locomotion. In particular, emphasis on the adaptive nature of locomotion provides new means for understanding processes of change, both on a developmental time scale as infants progress from crawling to walking, and in real time as babies make decisions from step to step.

The ideas in this chapter were inspired by two complementary tenets of Neisser’s work: an emphasis on ecologically valid, functionally relevant tasks, and a call to coordinate findings across traditionally disparate domains. Neisser (1982) argued that an obstacle to progress in perception and memory research has been a focus on isolated laboratory phenomena and domain-specific models. The accumulated facts typically bear little resemblance to everyday activities in real-world contexts. How might researchers overcome these limitations? The first challenge is to discover the important questions. This requires examination of behavior in tasks that capture the fundamental aspects of natural, everyday activities. The second challenge is to discover a broader unifying framework. The solution may lie in the connections between different domains of development (Neisser, 1994).

We have adopted these two tenets of Neisser’s work by focusing on the development of adaptive locomotion and by attempting to integrate several traditionally disparate domains of infant problem solving. Our debt to Neisser is also a practical one. Our empirical work for this chapter began at Emory University under Neisser’s tutelage. In fact, our first experiments were conducted in Neisser’s office. We pushed his desk and file cabinets into the far corners of the room, padded the walls and floor with rubber gymnastics mats, and placed in the center of the office an obstacle course for toddlers, complete with four differently textured slopes and stairs. Fortunately, Neisser was in England when we first constructed the padded playroom, and after his return, we moved our infant gymnasium to less auspicious lab space on the third floor of the Emory Baptist Church, but that is another story.
AN ECOLOGICAL STUDY OF MOBILITY

We illustrate the promise and feasibility of a functional, integrated approach to mobility with a large, longitudinal study of infants’ locomotion over slopes (Adolph, 1997). The basic plan was to create a laboratory analogue of everyday problem solving. We used a single locomotor task to observe concurrent changes in traditionally disparate research domains—biomechanical, perceptual, cognitive, and social—and a detailed longitudinal design to track changes over multiple time scales—from step to step, trial to trial, and week to week. As we describe next, results revealed a very different picture of developmental change from the traditional stage-like transitions between motor milestones and very different sorts of underlying mechanisms from the traditional emphasis on neuromuscular maturation.

Slopes. The slope task contained several essential ingredients. First, slopes are novel, allowing first-hand observation of how infants make adaptive decisions about the ground ahead. Babies have little exposure to slanted ground surfaces in everyday situations. Parents limit infants’ experience with ascent and descent by gating household stairs and closely monitoring infants when they clamber down furniture and ladders.

Second, steepness is a relative variable, providing a way to observe adaptive responding over developmental changes in infants’ bodies and skills. The slant of a hill is safe or risky depending on a set of objective, biomechanical constraints—infants’ current level of crawling or walking proficiency and whether the goal is to go up or down. Thus, the same relatively steep, risky hill for a weak and topy crawler can be a relatively shallow, safe hill for a strong and sturdy crawler. Likewise, the same safe hill for a proficient crawler can be relatively risky when the baby faces it from a new, more precarious, upright walking position.

In addition, relative risk depends on the direction of traversal. Biomechanically, infants’ bodies are better suited for crawling or walking uphill. Infants support their weight on a fully extended limb, requiring less muscle strength, and the moving limb contacts the hill midway through the swing cycle. Gravity naturally constrains forward momentum and infants’ hands are in a good position to stop a fall. In contrast, biomechanical constraints are more stringent for crawling or walking downhill. Infants support body weight on a bent arm or leg, requiring more muscle strength, and the moving limb travels a longer distance before contacting the hill. Infants must brake forward momentum to resist gravity and their hands are in an awkward position to catch themselves if they begin to fall.

Third, infants’ exploratory activity provides an avenue for understanding the basis of online decision making: There are multiple sources of information to specify whether hills are safe or risky for maintaining balance. For example, infants can obtain information about postural stability from optic flow as they perch on the starting platform or generate motion parallax as they peer over the edge. Touching the slope provides information about surface friction and slant from torques generated at wrists or ankles and shearing forces between the surface and infants’ hands or feet. Moreover, babies can test consequences for balance control by hanging on to their arms or legs over the brink, or exploiting other means of traversal. The most direct route is to plunge over and observe the consequences.

Fourth, multiple locomotor methods are possible on slopes, so that we can observe how new strategies enter infants’ repertoires and how babies select among them. On uphill slopes, infants can walk, clamber, or simply avoid going. On downhill slopes, babies can walk; crawl; slide down sitting, spread-eagled headfirst, backward feet first; or stay put on the starting platform. Backing is especially interesting because it involves an initial detour away from the goal as babies get into position and it involves relinquishing visual guidance because babies’ heads are pointed in the wrong direction.

Finally, the slope task simulated important elements of an everyday social context. The infants’ goal was to reach their parents, who waited at the top or bottom of the slopes offering their babies enticing toys and cheers. An experimenter stood nearby to rush to the rescue if infants began to fall. Regardless of outcome, trials ended with infants reunited with their parents amidst more praise and affection. Normally, parents would not put their babies on the brink of potentially risky slopes, and parents would provide explicit verbal coaching (e.g., “be careful,” “slide down”). In this task, however, parents maintained a positive demeanor on all trials and a constant stream of verbal praise and encouragement (e.g., “come on over here,” “you can do it”), and they never cautioned their babies or told them what method of locomotion to use. Nonetheless, the experimental arrangement allowed us to observe whether infants chose to figure out what to do on their own, sometimes appealed to adults for help, or required direct physical assistance from vigilant caregivers.

Longitudinal Design. The study was designed to control for duration of infants’ everyday locomotor experience, spanning the traditional locomotor milestones from the onset of independent mobility. Fifteen experimental babies were observed every 3 weeks, from the infants’ first week of crawling until several weeks after they began walking. Fourteen additional control infants were tested at three matched session times to control for experience on slopes in the laboratory (infants’ first and tenth weeks of crawling, and infants’ first week of walking). Thus, infants’ age and everyday locomotor experience were similar across experimental and control groups; only practice on laboratory slopes differed. Overall, there was a total of 221 test sessions and 7,325 trials on slopes.
Procedures. We tested infants' ability to cope with slopes on a large adjustable walkway. Starting and landing platforms were flat, but the middle section of the walkway sloped up or down in 2° increments from 0° to 36°. The walkway was cushioned with soft carpet and safety nets were strung along each side. Wooden posts at the corners of the starting and landing platforms provided infants with manual support for keeping balance. Infants began each 60s trial at one end of the walkway. Crawlers started each trial in a prone position, facing the hill from their typical crawling vantage point, and walkers started each trial in an upright position, facing the hill from their typical walking vantage point. Parents stood at the far end and encouraged their infants to come up or down, while an experimenter followed alongside infants to ensure their safety (Fig. 2.1). Trials ended after infants started onto the hill or after 60s, whichever occurred first.

At each test session, the experimenter used a psychophysical staircase method to identify the boundary between safe and risky slopes (Adolph, 1995, 1997). Slope boundaries were the steepest hills babies could crawl or walk up or down. The slope boundaries provided a measure of the objective biomechanical constraints on locomotion, as well as a way to compare responses across infants and across sessions relative to each baby's current level of crawling or walking proficiency.

The experimenter coded each trial online as success (crawled or walked safely), failure (tried typical method but fell), or refusal (slid down, climbed up, or avoided going). For the purpose of estimating slope boundaries, failures and refusals were treated as equivalent, unsuccessful outcomes. In general, the experimenter presented steeper slopes after successful trials, and she presented shallower slopes after failures or refusals. The process continued until the experimenter narrowed in on a slope boundary according to a 67% criterion (steepest hill with at least 67% successful trials, and at least 67% unsuccessful trials at the next 2° increment and all steeper hills). Easy baseline slopes (0° to 5°) were interspersed with more challenging ones to maintain babies' interest. All trials were videotaped for later analysis.

After testing on slopes, the experimenter obtained additional measures of biomechanical factors—infants' body dimensions and their crawling or walking proficiency on flat ground. Measures of infants' weight and height provided a crude index of size. Leg length and head circumference provided more detailed indices of body proportions, and Ponderal Index related infants' height and weight in an overall chubbiness index.

Coders scored infants' crawling proficiency on flat ground from videotapes of babies crawling back and forth over the flat walkway. More skillful crawlers have higher velocities and fewer crawling cycles (faster, larger movements). Coders calculated standard measures of walking proficiency from the footprints infants left as they walked over a strip of butcher paper with inked tabs on the soles of their shoes. Better walkers take larger steps and have smaller lateral distances (less splaying) between their feet.

Biomechanical Changes. There was a wide range in ages and styles when infants acquired independent mobility. Fifteen infants began as belly crawlers, making forward progress with their bellies dragging along the ground or hopping along in a sort of arm prop-belly flop pattern. Thirteen infants first crawled with a more erect hands-and-knees or hands-and-feet gait. All of the belly-crawling babies eventually crawled on hands and knees prior to walking. Onset ages for belly crawling ranged from 5.26 to 9.60 months and onset ages for hands-knees crawling ranged from 4.77 to 11.77. One control infant never crawled, but proceeded straight to walking. Overall, there was a wide range in ages when infants began walking independently (9.27 to 14.89 months). Infants' variable onset ages resulted in varying durations of total crawling experience (from 0.39 to 8.58 months) and a wide range in ages at each test session.

Infants' bodies and skills changed from week to week. Across sessions, all infants became bigger. However, babies' legs grew faster than their heads and torsos, so that the overall effect was more mature, less top-heavy body proportions. Similarly, height increased faster than weight so that Ponderal Index decreased, meaning that infants' bodies became more slender and cylindrical.
Infants' locomotor proficiency increased over weeks of crawling, and again over weeks of walking. On flat ground, infants' crawling velocity increased and number of crawling cycles decreased, meaning faster movements and larger crawling steps. Although babies showed improvements over both belly crawling and hands-knees crawling periods, in general, hands-knees crawling was more functionally efficient for moving on flat ground. Likewise, infants' footprints showed increase in step length and decrease in step width, indicating better postural control during periods of single limb support (e.g., Bril & Brenère, 1992, 1995).

Moreover, changing biomechanical constraints were reflected in infants' changing ability to locomote over hills. Slope boundaries depended on whether infants were going up or down and on the duration of infants' experience crawling on their bellies, hands and knees, and walking (Fig. 2.2).

Over weeks of crawling, slope boundaries increased. In general, going uphill was easier than going down. Belly crawlers were at an advantage for downhill slopes because they could slither down headfirst, oblivious to balance requirements. Uphill slopes were more difficult for belly crawlers because they could not support body weight on extended arms. In contrast,

![Graph showing changes in slope boundaries over weeks of locomotor experience for the three modes of locomotion (E = experimental group, C = control group). Note: From "Learning in the development of infant locomotion," by K. E. Adolph, 1997, Monographs of the Society for Research in Child Development. Copyright 1997 by the University of Chicago Press. Reprinted with permission.]

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hands-knees crawlers had more trouble going downhill, where keeping balance is crucial, but hands-knees crawling facilitated improvement in uphill boundaries, where infants could take advantage of their leg strength.

Over the transition from crawling to walking, infants' slope boundaries sharply decreased. The decrement was dramatic and uniform. In their first week of walking, infants displayed a narrow range of slope boundaries limited to very shallow hills. Over weeks of walking, slope boundaries steadily increased. As in crawling, going uphill was easier than going down.

Results showed expected correlations between the various biomechanical measures. Infants' body dimensions were related to their ages at crawling and walking onset. Bigger, faster babies tended to achieve each locomotor milestone later than smaller, slimmer infants. Infants' height, weight, leg length, and head circumference were positively correlated with age at crawling onset; height and leg length were positively correlated with age at walking onset. In addition, slimmer, longer babies were more proficient at crawling and walking on flat ground and on slopes. Better performance on flat ground predicted steeper boundaries on slopes, suggesting that the staircase estimates were reliable. Moreover, there were no differences in body dimensions, locomotor proficiency, or slope boundaries between experimental and control infants, suggesting that changes in infants' physical ability on slopes resulted from changes in their bodies and everyday locomotor skills, not from practice on slopes in the lab.

**Perceptual Judgments.** The critical perceptual question was whether infants could adapt responses to their current physical abilities on slopes. Changing slope boundaries meant that relative risk depended on each infant's current level of locomotor skill. If infants distinguished safe from risky hills, they should use their typical crawling or walking position on safe hills and select an alternative, less precarious position for risky ones.

A go ratio provided an index of the accuracy of infants' perceptual judgments. The go ratio was defined as the percentage of trials on which babies attempted their typical method of locomotion on hills steeper and shallower than their slope boundaries:

\[
\frac{(successes + failures)}{(successes + failures + refusals)}.
\]

Success is rare on hills steeper than infants' slope boundaries, by definition; therefore, go ratios on risky hills primarily reflect the ratio of failures to refusals. Likewise, failures are, by definition, rare on hills shallower than infants' slope boundaries, so that go ratios on safe hills primarily reflect the ratio of successes to refusals.

At the slope boundary, the go ratio is ≥ .67, by definition. However, the ratio varies freely from 0 to 1 on slopes shallower and steeper than the
boundary. Perfect perceptual judgments would imply two patterns: (a) a high go ratio on safe hills shallower than the slope boundary, where probability of success is high; and (b) a low go ratio on risky hills steeper than the slope boundary, where probability of falling is relatively high. Infants might err on the side of caution with a low ratio on perfectly safe slopes, or they might err on the side of boldness with a high ratio on risky hills.

In addition, adaptive responses should show lower go ratios on risky downhill slopes compared with up. Falling while going downhill was relatively aversive, and the experimenter had to rescue infants to prevent injury. In contrast, failures while going uphill were relatively inconsequential because babies could catch themselves if they began to fall.

Infants' perceptual judgments reflected the different task constraints of going up versus down. On uphill trials, infants often attempted hills where they were likely to fall, despite falling on previous trials and in previous sessions. Crawlers usually struggled at the base of impossibly steep uphill slopes for the entire duration of the trial, sometimes getting partway up, then sliding back down. After lengthy frustrated attempts, they tried equally hard moments later at the next impossibly steep slope. Walkers usually adopted a similar strategy, getting a running headstart on two feet and flinging themselves at impossibly steep inclines. Sometimes persistence paid off and infants eventually reached the summit, and infants were able to catch themselves on trials where they fell. As a result, week after week, both for crawling and for walking, infants' average go ratios were close to 1.0 on safe and risky hills alike (top panel of Fig. 2.3). In fact, there were only three uphill protocols in the entire data set where infants' go ratios on risky slopes decreased below .50.

In contrast, perceptual judgments on downhill trials showed a very different pattern. Go ratios showed two learning curves, one over weeks of crawling and one over weeks of walking (bottom panel of Fig. 2.3). In their first weeks of crawling, infants plunged over the brink of impossibly risky downhill slopes, requiring rescue by the experimenter to prevent babies from tumbling headlong; on average, risky go ratios were high at .68. Over weeks of crawling, infants became increasingly discriminating, attempting only safe hills and refusing to crawl down risky ones. For babies who began crawling on their bellies, go ratios continued to improve over the transition from belly to hands and knees. By their last weeks of crawling, perceptual judgments became nearly perfect; average go ratios on risky hills were .11.

Surprisingly, there was no transfer from crawling to walking. When the same discerning crawlers faced downhill slopes the next week from their new, upright walking position, again they went right over the precipice. In the first weeks of walking, average go ratios were just as high as in infants' first weeks of crawling, near .65. Then, infants learned all over

FIG. 2.3. Infants' perceptual judgments over weeks of locomotor experience for uphill (top panel) and downhill (bottom panel) slopes. Go ratio = (successes + failures)/(successes + failures + refusals). Trials are grouped into safe (shallower) versus risky (steeper) hills relative to infants' slope boundaries. Note: From "Learning in the development of infant locomotion," by R. E. Adolph, 1997, Monographs of the Society for Research in Child Development. Copyright 1997 by the University of Chicago Press. Reprinted with permission.
again to distinguish safe from risky hills as walkers. Over weeks of walking, go ratios on risky downhill slopes gradually geared in to infants’ slope boundaries, decreasing to .24 by week 13 of walking. Decrease in go ratios was no faster the second time around.

In fact, we were so surprised to see formerly cautious crawlers responding indiscriminately to risky slopes as walkers that we added an additional experimental manipulation. At the end of each downhill walking protocol, the experimenter tested infants’ judgments in both postures over six consecutive trials on the steepest 36° slope (two trials in their new upright posture, two in their old familiar crawling position, then two from a walking position again). Over half the children showed failure to transfer from trial to trial. They went straight over the brink in an upright position, then slid down safely when facing hills from their old crawling vantage point, then again went over the edge in a walking position. Occasionally, when the experimenter started babies in a prone, crawling position, infants stood themselves up and walked over the edge, as though preferring to be helpless walkers rather than discerning crawlers. Examination of consecutive trials at other incremenis of slope showed similar results. After falling at one increment, babies were most likely to attempt the same precarious position on the same hill, moments later on the very next trial. There was no evidence of within-session learning to prompt adaptive responses.

Apparently, infants learned to gauge their abilities on slopes from crawling and walking over flat ground during everyday experiences at home. There were no differences between experimental infants exposed to dozens of trials each month on slopes in the laboratory and control infants who only came to the laboratory three times. Moreover, duration of everyday locomotor experience (number of days since onset of crawling or walking) was a stronger predictor of infants’ go ratios than infants’ test age or any other variable. Learning, however, required vast exposure to everyday crawling and walking. On average, infants’ go ratios on risky hills did not decrease below .30 until the sixteenth week of crawling and the thirteenth week of walking.

**Exploratory Activity.** Because crawling and walking boundaries changed from week to week, infants’ increasingly adaptive go ratios on downhill risky slopes could not have resulted from simple associative pairing between a particular behavior and a particular degree of slant. Rather, infants’ go ratio curves suggest that infants’ decisions were based on information obtained online at the start of each trial.

To examine the informational basis for infants’ decisions, coders scored infants’ exploratory activity on the starting platform. Latency to begin traversal provided an index of the duration of infants’ visual exploration. In addition, coders noted whether infants maintained orientation of head and eyes toward the landing platform. Frequency of touching slopes with hands or feet provided a measure of infants’ haptic exploration. Coders included only active touch accompanied by visual exploration, where infants rubbed or patted the slope or rocked over their hands or feet at the brink, all while maintaining orientation of head and eyes in the direction of traversal. Each measure of exploratory activity was calculated independent from slope boundaries and go ratios. Exploration reflected infants’ behavior before they started onto slopes, whereas slope boundaries and go ratios were determined by infants’ behavior after they crossed the brink. In principle, refusal did not require prolonged exploration (e.g., infants could immediately choose an alternative method and slide down hills), and successes and failures did not prohibit prior exploration (e.g., infants could hesitate and touch hills, then plunge heedlessly over the brink nonetheless).

Overall, infants were extremely selective in distributing their exploratory behaviors. Long looks and frequent touches were rare. On most trials throughout the duration of the experiment, infants started onto slopes after only a brief glance. Median latencies were a tenth of a second and the median number of touches per slope was 0.

As in previous experiments (Adolph, 1995; Adolph, Eppler, & Gibson, 1999), exploration on uphill slopes was most rare and most indiscriminate. In most cases (over 80% of uphill trials), babies began dashing onto hills as soon as the experimenter released them at the start of the trial (top panel, Fig. 2.4). This means that infants’ judgments were based only on a momentary glance as the experimenter lowered babies toward the starting platform. As shown in the figure, long looks and touches prior to ascent were limited primarily to the first 4 weeks of crawling. However, in these sessions, babies hesitated and touched safe and risky hills indiscriminately and exploratory looking and touching were rarely followed by refusals. In subsequent weeks of crawling and walking, infants flung themselves forward onto hills nearly as soon as the experimenter placed them on the starting platform.

In contrast to uphill trials, infants explored more before going down hills (over 40% of downhill trials) and over sessions, infants’ exploratory behaviors became more discerning (bottom panel, Fig. 2.4). Infants’ latency and touching showed a gradual gearing in toward risky hills steeper than their slope boundaries. As in previous studies (Adolph et al., 1993; Eppler, Adolph, & Weiner, 1996), infants explored more when they were new crawlers than when they were new walkers. In their first weeks of crawling, infants’ latency and touching were relatively high and distributed over both safe and risky downhill slopes. Over weeks of crawling, there was a steady decrease in latency and touching on safe and risky hills, no change from low levels of exploration over the transition from crawling.
to walking, and gradual increase in exploration on risky hills over weeks of walking.

Moreover, as infants’ exploratory activity on downhill slopes became more selective, it also became more efficient. Across sessions, infants’ exploratory activity and go ratios changed in tandem. Over weeks of crawling, latency and touching on risky hills paralleled infants’ go ratios. All three measures showed increasing specificity as values geared in toward risky hills. This means that crawlers actually explored less as their responses became more adaptive. Over weeks of walking, latency and touching on risky hills mirrored infants’ go ratios. Exploration on risky hills increased as go ratios decreased.

Usually, infants hesitated for several seconds prior to their first touch, suggesting that visual information prompted the touch; average latency before infants’ first touch was 6.08 s. The most popular touches were rocking or stepping movements with hands or feet as infants rotated over their wrists or ankles. Rocking movements were most nerve-wracking to observe because infants perched right at the brink of the hills and their bodies sometimes rotated more than 90° over their supporting limbs. In addition, infants occasionally obtained haptic information by patting, rubbing, or poking the hill with a hand or foot, keeping the knees or a foot on the starting platform while the moving limb probed the slope ahead.

Cognitive Strategies. After infants had decided that hills were risky for their typical crawling or walking method, they were left with the problem of figuring out an alternative way to go. On refusal trials, infants could discover a viable means of travel during the course of the trial, or retrieve a suitable climbing or sliding position from the existing options in their repertoires.

The least imaginative solution was avoidance. Infants always had the option to simply stay put on the starting platform until the end of the trial. However, avoidance was frustrating and it was infants’ least preferred alternative. On impossibly steep upward hills, infants had few choices: attempt to clamber up on all fours or avoid going. Overall, infants avoided ascent on less than 2% of uphill trials. Instead, crawlers attempted a futile crawling position and walkers attempted to go upright or switched to crawling. In fact, remaining stuck on the starting platform was so frustrating that infants occasionally detoured off the end of the starting platform and crawled or walked around the apparatus to their parents at the far side.

On risky downhill trials where more options were available, infants replaced avoidance responses with various sliding positions. In infants’ first weeks of crawling, they avoided descent on 100% of refusal trials. By their last week of crawling, avoidance decreased to 1% of refusal trials and avoidance remained under 9% of all refusal trials over weeks of walking.
However, avoidance was never replaced by a single preferred sliding position. Instead, each baby used a flexible variety of sliding positions on refusal trials in and across sessions: sliding in headfirst prone, sitting, and backing positions over weeks of crawling, and all of the sliding methods over weeks of walking. Across sessions, nearly every infant used each of the sliding positions at least once. More striking, within sessions, most infants used more than two sliding positions in their last weeks of crawling and over all weeks of walking. Variety in locomotor methods was linked with the adaptiveness of infants’ responses. Infants using more methods tended to have lower go ratios.

On some downhill trials, infants shifted smoothly to an alternative position and immediately slid down, as though retrieving a known solution from their repertoire of locomotor methods. However, many downhill trials revealed a more exploratory selection process. Similar to the means/ends exploration observed in object tasks (e.g., Piaget, 1952; Wilsatts, 1989), infants sometimes explored various means of traversal by testing various sliding positions while still on the starting platform. Babies sometimes sat down and hung their legs over the brink, or pivoted into a backing position and looked over their shoulders down the hill, and so on. Coders measured this sort of means/ends exploration of different locomotor methods by counting the number of discrete shifts in position before infants started onto slopes. Refusals required zero shifts to avoid traversal, and only one shift for an alternative climbing or sliding position. Multiple shifts would suggest that children explored various means of reaching the landing platform by testing what different positions felt like before committing themselves to going.

Means/ends testing was especially important for selecting among head-first, sitting, and backing descent methods. Sliding headfirst was easiest but ended most often in a mishap at the bottom of the hill. Sliding in sitting or backing positions were more difficult cognitively, but were safest. Although every baby could sit independently from the first weeks of testing, infants had to view the sitting position as a means of locomotion rather than a stationary posture. Backing was even more complex. From their first weeks of testing, every baby had the requisite components for using the backing position (shift to a prone position, pivot in circles on their bellies, push backward). However, the backing position required infants to execute an initial detour away from the landing platform, then scoot backward with their faces turned away from the goal. In fact, sliding head-first prone was infants’ first sliding position, and sitting and backing positions appeared last in infants’ slope repertoires.

Multiple shifts in position increased over weeks of crawling and walking (Fig. 2.5). Average number of shifts exceeded 1.0 after infants’ sixteenth week of crawling and after their thirteenth week of walking, suggesting that babies actively explored various ways to go down. In most cases, multiple shifts resulted in selection of an alternative sliding position (75% trials) rather than avoidance. Moreover, most shifts in position followed long latencies and tics, and nearly every shift trial (99%) resulted in refusals, suggesting that infants shifted position after deciding that hills were risky for their typical method of locomotion.

Walking infants showed an additional type of means/ends behavior by use of the posts at the corners of the starting platform. Similar to adults’ use of a railing to navigate a tricky patch of ground, walking infants some-
times used the posts at the brink of the hill for manual support while shifting position or touching the slope with their feet (10% of shift trials and 22% of touch trials). Apparently, threats to balance control led infants to view the posts as a simple tool or means enroute to the goal.

Social Context. The slope task simulated important elements of an everyday social context. During each trial, an experimenter followed alongside infants to provide assistance if necessary. The baby’s goal was to reach their parents, who offered a steady stream of positive encouragement and directed infants’ attention to attractive toys and cheerios waiting at the end of every hill.

The go ratio curves for uphill and downhill protocols showed that infants did not learn to rely on the experimenter for rescue. Although the experimenter stood nearby on uphill trials, all infants safely caught themselves if they began to fall. On downhill trials, the experimenter did rescue infants on every occasion where they began to fall, and these near falls appeared to be relatively aversive. However, over the sessions infants became more cautious rather than more reckless, suggesting that infants learned to rely on their own judgments about safe versus risky hills.

More interesting were infants’ social expressions directed to their parents and the experimenter. Despite adults’ constant positive demeanor and verbal encouragement on every trial, infants could choose to appeal to their parents or the experimenter for help. Coders scored infants’ social expressions on the starting platform by the frequency of infants’ vocalizations (babbling, whining, and crying) and infants’ gestures (pointing at the slope, head shakes “no,” arm gestures to the parents such as “gives” and “pick-me-ups,” and clinging to the experimenter’s body or arm).

Overall, infants emitted social expressions on 16% of trials. Frequency of social expressions was comparable to infants’ rate of exploratory touching (16% of trials), but on most trials infants started on hills without a peep. (Note: Social expressions tended to occur on touch trials, but sometimes infants touched without emitting social expressions and sometimes they emitted social expressions without touching.) Preliminary analyses indicate that vocalizations and gestures became increasingly geared to task constraints (Stergiou, Adolph, Alibali, & Cenedella, 1997). Similar to infants’ patterns of exploratory looking and touching, crawlers displayed more social expressions than walkers, and social expressions were initially most indiscriminate. Infants emitted most social expressions in their first weeks of crawling, and did so on both uphill and downhill, safe and risky slopes. Over weeks of crawling, social expressions gradually became limited to risky downhill slopes. Levels of social expressions remained relatively low over the transition from crawling to walking and, over weeks of walking, social expressions increased slightly on risky downhill slopes. Surprisingly, experienced crawlers gestured equally often as walkers, despite crawlers’ reliance on hands and arms for locomotion. In other words, crawlers shifted to sitting or kneeling positions to use their arms for social expressions rather than balance control.

Differential social expressions in experienced crawlers and walkers provide additional evidence that infants eventually discriminated safe from risky hills. These results suggest that infants may contribute to the maintenance of their safety by emitting differential amounts of social expressions in potentially risky situations. Furthermore, regardless of infants’ intentions when they vocalized or gestured in early weeks of crawling and walking, adults interpreted their behaviors as expressions with social intent. In everyday situations, even indiscriminate social expressions may function to alert parents when infants are on the move.

Moreover, the slope task was nested in a larger social context—infants’ changing exposure to ascent and descent tasks at home. Parents filled out a daily diary noting infants’ home experience going up and down stairs and clambering down from furniture. Frequency of exposure to ascent and descent was constrained by the layout of infants’ homes and by parents’ decisions to allow their babies access to various ascent and descent situations. For example, parents of beginning crawlers babyproofed their homes by gating household stairs and parents permitted babies to go up stairs before they allowed infants to come down. Coders scored frequency of experience with ascent and descent as the number of entries in parents’ diaries between each crawling or walking session divided by the total number of days between sessions.

Infants’ home experience with ascent and descent increased over weeks of crawling and over weeks of walking. At best, infants were exposed to home stairs and furniture on half of the days between test sessions, and long-time crawlers had more home ascent/descent experience than infants who crawled for only a short time. In addition, infants tended to have more experiences going up stairs than going down as crawlers and more experiences descending furniture than ascending stairs as walkers. Infants with stair experience always went up in a crawling position and most went down in a backing position (2 babies bumped down in a sitting position). All infants with experience descending furniture went down backward feet first.

In infants’ last week of crawling, duration of crawling experience, amount of home ascent/descent experience, and age varied freely. In that target session, home experience going up and down stairs and furniture was correlated with infants’ test age, body dimensions, and crawling proficiency on flat ground. Apparently, parents provided their babies with access to potentially risky ascent and descent situations at home when babies were older, were more maturely proportioned, and displayed more
UNDERSTANDING CHANGE IN INFANT LOCOMOTION

Coping with slopes required flexible problem solving. Infants’ growing bodies and changing locomotor skills resulted in weekly changes in their physical abilities to go up and down slopes. Adaptive mobility meant that infants matched their locomotor responses to these changing biomechanical constraints. The only way for infants to make online decisions about safe versus risky hills was to obtain information from their own exploratory movements. Despite infants’ occasional appeals for help, parents and experimenters left infants to figure it out for themselves. Moreover, in the case of risky hills, infants also had to decide which alternative method of locomotion to use.

Learning From Everyday Locomotor Experience. What spurred adaptive responses on slopes? Traditionally, researchers accounted for locomotor development with single cause, maturational mechanisms linked with infants’ ages or stages of postural control. However, our focus on adaptive locomotion suggests a more complex explanation. If age were the sole impetus for change, we would expect one smooth go ratio curve on risky hills over weeks of crawling and walking. If adaptive responding resulted from the stage-like transition from crawling to walking, perhaps driven by the shift from a more stable quadruped posture to a less stable upright one, we would expect high go ratios on risky hills over weeks of crawling and an abrupt decrease in go ratios after walking onset. Instead, change resulted from learning via everyday locomotor experience. Infants showed two go ratio curves on risky downhill slopes, one over weeks of crawling and one over weeks of walking, and infants showed increasing sensitivity to the different biomechanical constraints of going uphill versus going down. Duration of crawling or walking experience over flat ground at home was the strongest predictor of infants’ perceptual judgments and exploratory behavior on slopes. However, as described later in this chapter, physical growth, locomotor proficiency, and infants’ age may also play a role.

What Infants Learn. What might infants learn from everyday crawling and walking experience? A likely answer is that infants learn to predict whether they are going to lose their balance. Detecting threats to balance control requires information about the limit of permissible postural sway. Infants will fall over if their body moves outside their base of support without sufficient muscle strength to pull themselves back into position. When the ground is too steep (or too slippery or too compliant), infants must reduce postural sway by stiffening their bodies or, in extreme cases, switch to a different method of locomotion. Exploratory looking and touching movements yield information about whether the ground surface is safe or precarious for keeping balance in infants’ current crawling or walking posture. Exploratory means ends shifts in position yield information about balance control in alternative climbing and sliding positions when infants decide that their typical method of locomotion is impossible.

Results suggest that infants may learn to detect information for permissible sway posture by posture rather than task by task, such that information obtained from exploratory looking and touching movements generalizes to new ground surfaces and to changes in infants’ body dimensions, but is specific to well-practiced postures and vantage points. Everyday practice of keeping balance in a crawling posture, for example, may help infants to gauge how fast and far their bodies can rotate as they sway back and forth over their wrists, and how much muscle force infants can muster to counter rotational forces. Such learning would transfer to a novel crawling task. However, in an unfamiliar upright posture, all bets are off. Walkers’ bodies sway around the hips or ankles rather than the wrists, compensatory sways are generated primarily in leg or back muscles rather than the upper body, and infants’ base of support is reduced to the space between their feet.

Accordingly, infants in this study showed both impressive generalization from home crawling or walking experience to crawling or walking over slopes and a striking lack of transfer between crawling and walking postures. Despite weekly changes in infants’ crawling styles and crawling proficiency, crawlers’ go ratios decreased and their exploratory behaviors became more discerning. Likewise, despite weekly changes in infants’ walking ability, go ratios decreased and exploratory behaviors became more efficient. However, over the transition from crawling to walking, perceptual judgments and functional outcome of exploratory movements were impaired.

Online Problem Solving. In the end, adaptive locomotion requires infants to make online decisions. The end product of development is the ability to monitor action adaptively, online, from one step to the next. The data suggest that what infants learn from everyday home experience is a repertoire of increasingly effective exploratory movements for obtaining information about balance control as infants face each new surface a few steps ahead.

Most often, infants started onto slopes after only a brief glance at the hill. Nearly every uphill trial and more than half of the downhill trials had
latencies of less than 1 s. This means that infants decided on a locomotor method as they were lowered toward the starting platform, sometimes their typical crawling or walking method and sometimes an alternative position. The functional outcome of quick glances improved dramatically over weeks of experience; failures decreased, and successes and refusals increased. Information gleaned from a quick look may include the distance of the surface from infants’ eyes or the angle of slope relative to the plane of gaze.

If a brief glance hinted at something amiss, infants paused for a longer look. Infants typically maintained orientation toward the landing platform during the time that they hesitated. Across sessions, long looks were followed by infants’ typical method and alternative locomotor methods in approximately equal proportions, and the functional outcome of long looks improved with weeks of experience. Prolonged looking involves movements of infants’ eyes, heads, and bodies as they generate compensatory postural sway on the starting platform and peer over the edge. These movements produce visual and mechanical information for balance control (e.g., Lee, 1994; Mark, Baillie, Craver, Douglas, & Fox, 1990) and visual information about the properties of the ground ahead.

When concerted looking suggested risky ground, infants obtained additional information from touching. Most touches followed long looks, suggesting that visual information prompted the touches. Infants probed the slope with hands and feet—usually stepping and rocking movements at the brink of the hill—all while looking at their limbs and the ground. Over weeks of crawling or walking, touches became increasingly efficient. They were shorter in duration and more likely to be followed by successes or refusals rather than failures. Coordinated looking and touching yields information about the slant and friction of the hill by generating rotational forces at wrists or ankles, shearing forces between the limb and the surface, and additional visual information from optic flow patterns and motion parallax.

When exploratory looking or touching suggested danger from falling, children explored alternative locomotor methods. Shifts in position were followed by refusals, indicating that infants had already decided that slopes were risky. On most trials, infants discovered an appropriate alternative and used it. Over weeks of crawling, infants replaced avoidance responses on downhill slopes with alternative sliding positions and they continued to use their sliding positions over weeks of walking. Apparently, means/ends exploration yields information for keeping balance in less practiced locomotor postures, such as the various sliding positions for going down hills.

Characterizing Change. Infants showed a protracted period of learning enroute to adaptive, online decisions on slopes. Most researchers have characterized infant learning as an additive, enrichment process of construction via transformation of schema or simple associative pairing (e.g., Piaget, 1952; Rovee-Collier, Greco-Vigorito, & Hayne, 1993). A construction process means that children build the requisite knowledge from the ground up by sequencing or reorganizing smaller, component movements in their repertoires. For example, in the slopes task, a construction process would be evidenced by a gradual increase in exploratory behaviors as infants compile the full array of movements required for online decision making.

The slopes data, however, point to an alternative characterization of learning as a subtractive, sculpting process of gradual differentiation and selection (Gibson, 1969, 1988, 1991; Gibson & Gibson, 1955). A differentiation/selection process implies two things. First, the essential information for adaptive decision making must be available from the beginning of independent mobility. That is, physiological sensitivity and ability to execute appropriate exploratory movements are prerequisite for a differentiation/selection process to operate. Second, a differentiation process would predict that within sessions, infants’ responses should be graded, with infants’ most accurate judgments on hills most remote from their slope boundaries and infants’ least accurate judgments on hills most similar to their slope boundaries. Across sessions, a differentiation/selection process should show increasing specificity as exploratory movements and locomotor responses become more honed and efficient. Given the raw materials to start, the developmental task is to obtain the necessary information, understand its relevance for locomotion, and select an appropriate locomotor response.

Consistent with a differentiation/selection process, the evidence indicates that information for balance control is available at the start of mobility. Even neonates show physiological sensitivity to visual information for surface slant. Infants looked differentially at displays of surfaces slanting to different degrees (Slater & Morison, 1985). Moreover, infants have the requisite skills for obtaining visual and haptic information for slant via self-initiated exploratory movements. In cross-sectional studies, newly crawling infants exhibited differential visual and haptic exploration on steep hills compared with shallow ones in both locomotor and nonlocomotor tasks (Adolph et al., 1993; Eppler et al., 1996). Likewise, in the current study, babies executed the full range of exploratory looking and touching movements in their first weeks of crawling. However, the data suggest that sensitivity and differential exploration is not enough for adaptive responding. Infants must learn the relevance of information obtained from exploratory looking and touching. In the current study and in previous experiments (Adolph et al., 1993), new crawlers explored steep and shallow hills differentially, but plunged over the brink of impossibly steep hills nonetheless without testing a single alternative sliding position.

In accordance with the differentiation/selection account, infants’ perceptual judgments were graded in sessions and showed increasing attune-
ment across sessions. In each session of crawling and walking, infants’ judgments were always most accurate on the riskiest hills most remote from infants’ slope boundaries, and most indiscriminate on slopes slightly steeper than slope boundaries. The most dramatic learning across sessions was on hills slightly steeper than infants’ slope boundaries. Likewise, infants’ exploratory movements showed a pattern consistent with a differentiation process. Exploratory looking and touching were scaled to infants’ slope boundaries, showed increasing specificity across sessions until exploration was limited to risky hills, and showed improvement in functional outcome of trials following each type of exploratory movement. Infants in cross-sectional samples also showed graded perceptual judgments and exploratory behaviors (e.g., Adolph, 1995). Apparently, infants must learn to glean the relevant information for accurate judgments.

**Mediating Effects of Biomechanical Factors.** A central problem for a differentiation/selection characterization of learning is an account of how so much information becomes available so early. What factors might prompt infants to generate appropriate exploratory movements to enable them to distinguish safe from risky terrain? Presumably, if infants’ early exploration in their first weeks of crawling resulted from deliberate forethought, beginning crawlers also should have shown adaptive responses on perilously risky hills. Likewise, if new crawlers’ high levels of social expressions reflected functional knowledge of the consequences of risky slopes, infants should have avoided traversal. Results of the current study suggest that useful exploratory movements, social expressions, and locomotor methods may originate in a serendipitous confluence of biomechanical factors. Infants’ changing body dimensions, variable movements, and the physical constraints of the ground surface can load the deck for spontaneous emergence of new motor patterns. Like cases of exaptation in evolutionary development, infants may discover functionally useful movements in the course of attempting to do something else. Discovery in this case does not require deliberate forethought, only that infants must recognize a good thing once they have got it.

In fact, mediating effects of biomechanical factors may explain infants’ relatively indiscriminate, high levels of exploration and social expressions in their first weeks of crawling and infants’ low levels of exploration and social expressions in their first weeks of walking. In their first weeks of crawling, most infants were weak, top-heavy, and poorly proficient. Infants’ heavy heads kept their eyes pointed toward the ground and their weak arms kept body weight distributed back toward the legs from step to step. Even on flat ground, infants hobbled along, pausing, patting the floor, and rocking back and forth over their wrists between bursts of crawling steps (e.g., Goldfield, 1993). Initially, beginning crawlers may have exe-

cuted the same looking and touching movements on the brink of slopes as they did on flat ground due to the biomechanical constraints of their new quadrupedal posture. Infants could look at the floor, sway to and fro, and generate torques around their wrists without understanding the relevance of these movements for guiding locomotion. Thus, exploratory movements may have entered infants’ repertoires serendipitously, and later, after weeks of crawling, infants used the same exploratory movements intentionally to obtain information about the ground ahead.

Likewise, gathering sufficient energy to move forward meant that new crawlers were in a relatively high state of arousal. Infants’ first vocalizations in the slope task may have emerged spontaneously as a result of overall physiological arousal. Later, infants’ more specific use of vocalizations, arm gestures, and clinging behaviors reflected functional appeals for help. Furthermore, in this case, function may precede intention. Regardless of their intent, infants’ vocalizations function to alert caregivers when infants are in transit, and adults in the slope task responded to all whining and babbling vocalizations as intentional social expressions.

Biomechanical constraints may also explain the low levels of exploration in infants’ first weeks of walking. New walkers have especially poor balance control during periods of single leg support (e.g., Bril & Brenière, 1992, 1993). Infants’ body weight shifts forward with each step, so that infants must quickly place their moving leg before they fall over. Unlike crawling, there is no serendipitous, safe pause in forward momentum at the brink of a risky surface. This means that walkers must have decided ahead of time to stop and touch slopes; once their leading leg was planted over the brink, it was already too late. In contrast to crawling where the head naturally points downward and infants have to work against gravity to lift their heads, in upright locomotion, the natural position for head and eyes is straight ahead. Rotating the head downward shifts infants’ center of mass forward and threatens balance control. Instead of pausing, looking, and touching serendipitously, new walkers could only have stopped to look or touch hills based on their initial glance as they were lowered toward the starting platform. In fact, even experienced walkers may have had difficulty keeping upright balance while executing exploratory peering movements and touching movements with their feet. Many experienced walkers held the corner posts at the brink of slopes while peering downward or touching hills with their feet, as though requiring additional support to keep balance. In contrast, only one crawler on only one trial held a post for support.

A similar serendipitous biomechanical scenario may also explain the origins of new locomotor movements. Like exploratory movements and social expressions, new locomotor methods may emerge spontaneously in the context of doing something else. For example, changing biomechanical
constraints may have facilitated spontaneous discovery of new descent methods by placing infants in opportune, new situations. Most infants appeared to discover the backing position on slopes by accident, in the course of trying to crawl down steep hills (Wechsler, 1995; Wechsler & Adolph, 1995). As infants' bodies became more maturely proportioned and as their crawling proficiency improved, infants spent more trials on steep slopes. Accomplished crawlers started down on hands and knees with their arms stiffly extended in front, legs tightly flexed under their buttocks, and weight pushed back toward their rumps. Gravity pulled infants’ legs around until babies found themselves sliding down sideways or backward feet first. Infants sometimes said, "uh oh" or "oh no" and several infants crawled back up to the starting platform and looked down the hill in puzzlement. After experiencing one or more serendipitous backing trials, infants began executing the backing position on purpose before leaving the starting platform.

It is important to note in these examples that infants’ behaviors were not random thrashing or trial and error learning. But, in their first incarnation, neither were behaviors necessarily deliberately focused toward their functional relevance. Instead, infants' repertoires of exploratory movements, social expressions, and locomotor methods may emerge in the context of a goal directed task, with inherent variability in the system. The origins of such basic tools for solving the problem of mobility may be overdetermined by the visititudes of development. Once in infants’ repertoires, recognizing the functional relevance of these movements is hard won over weeks of crawling and walking.

CONCLUSION

The problem of mobility was of central concern for developmental psychologists in the first half of this century. Traditional research programs focused on neuromuscular changes in the biomechanics of locomotion. Divorced from everyday function for the past 50 years, infant locomotion was relegated to descriptions of age norms and postural stages outside the central issues of psychological development. Only recently have researchers begun to overcome the conceptual obstacles of monolithic change mechanisms and oversimplified laboratory tasks.

Our aim in this chapter was to illustrate a new research agenda for understanding how infants solve the problem of moving. As Neisser (1982) argued, the real challenge is to design ecologically valid, functionally relevant tasks that lead investigators to discover the important questions. Further, an integrated approach that examines behavior across traditionally disparate domains may point toward more general theories of learning and development.

2. INFANT PROBLEM SOLVING

POSTSCRIPT

In his book, Memory Observed, Neisser (1982) shared an adage, "Education is what is left over when you have forgotten what you have learned" (p. 5). We wish to reassure our teacher that we have not forgotten all the important lessons. For example, Neisser emphasized clear communication skills in his students. One way that he operationalized good writing was the eight-letter rule. Drafts of our writing returned from his desk with all lengthy, awkward, technical terms circled. One memorable episode was when we asked Neisser to help fund the mailing of our first feedback letter to parents. He agreed to pay, but there was a stipulation: We first had to pay him 5 cents for every word over eight letters long. The newsletter was quickly rephrased so that parents could actually understand the findings.

We end with a personal note to Dick. A quick check of this manuscript indicates that we have violated the eight-letter rule to the tune of 56 dollars and 5 cents. Should we pay you now or is there time for one more revision?

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REFERENCES


Descriptions of Orientation and Structure in Perception and Physical Reasoning

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In every species that has cognition, individual organisms take account of the orientations of things (see Fraenkel & Gunn, 1940). Ants leave their nests and search great distances for food or for other ant colonies. How does an ant find its way back? It appears that ants see stripes in the sky, due to their sensitivity to the polarization of sunlight. As an ant forages, its average heading is encoded as an angle relative to the stripes in the sky (e.g., Schone, 1984). To return home, the ant reverses direction.

Human use of information about the world is extended over space and time and has flexibility beyond that of other species. When a human behaves, it may be to determine the age of a fossil, to move a single atom a few microns, or to launch mechanical sensors into the atmosphere of another planet. But despite our differences from ants, understanding orientation is as important to us as it is to them. Along with most other vertebrates, for example, we have a vestibular sensory system dedicated to perception of the local vertical. Much of our cortical organization involves orientation-sensitive neurons or populations of neurons (see Kandel, Schwartz, & Jessel, 1995). Our perceptual intuitions readily inform us that a hill is steep, that a picture frame is tilted, or that a stack of books is leaning too far over. Everyday language encodes these terms: steep, tilted, and leaning, and many more besides. Metaphors based on orientation are common in language (e.g., Lakoff & Johnson, 1980). We are inclined to things, make oblique references, try to get the best angle, to be an upright person, and to avoid the slippery slope of a tempting argument. As humans...