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Infants on the Edge: Beyond the Visual Cliff

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The Backstory

Eleanor Gibson told her students several stories about the origins of the visual cliff paradigm (also described in Gibson, 1991, 2002). In one rendition, Gibson first began thinking about infants at the edge of a cliff during a family road trip to the Grand Canyon in the mid-1940s. She worried about her two young children playing near the rim, although her husband, perception psychologist James Gibson, assured her that they were sensitive to the visual information for depth. (Later, JJG told the story to students, somewhat gloating that his wife's research had proven him correct.) In a second rendition, Gibson learned that some species of animals avoid a drop-off shortly after birth. While preparing newborn goats for experimental and control groups at the Cornell Behavior Farm circa 1950, she panicked about where to put the first, carefully washed twin goat while birthing the second one. The farm manager told her to put it on the top of a high camera stand. Gibson worried that it would fall off, but the newborn kid stood upright on the tiny pedestal until she finished birthing and washing the second twin. A third story took place in the mid-1950s. After the grueling process of dark-rearing rats for studies on visual form discrimination with collaborator Richard Walk, Gibson hoped to maximize their efforts by running the animals in a second study. Remembering the Grand Canyon anecdote, Walk suggested depth discrimination, but how to test it? Lashley and Russell's (1934) famous experiments with dark-reared rats on a jumping stand required days of training in the light. To avoid the training period, Gibson and Walk decided to observe their rats at the edge of a cliff immediately upon emerging into the light. The experiment required a new apparatus they dubbed the "visual cliff"—"cliff" because there was a simulated drop-off and "visual" because they attempted to eliminate all other information for the drop-off (Gibson, 1970).

Regardless of the source of inspiration for the paradigm, in the 1950s, rearing animals under altered environmental conditions was a popular method for assessing the role of experience in development. The visual cliff, conceived by Gibson and Walk as a test of visual depth perception in dark-reared rats, seemed an appropriate way of addressing the age-old question of whether perception of space requires visual experience. Their first publication (1957, *Science*) reported findings from the dark-reared rats, and on its heels came the 1960 *Scientific American* article with the famous photographs of infants and kittens on a checkerboard surface peering over the edge of a precipice. Their most scholarly work, the 1961 monograph, described all of their comparative studies.

The Visual Cliff

The first (rat-sized) visual cliff apparatus was jerry-rigged by Thomas Tighe (Gibson and Walk's research assistant) with found objects during a party: pieces of glass, wood, rods, clamps, and patterned wallpaper (or linoleum tiles or checkered table cloth, depending on who Gibson told the story to). A raised (8 cm high), narrow, wood centerboard divided the glass into two equal sides and served as the starting platform. The wallpaper was placed directly beneath the glass on the "shallow" side and far below the glass on the "deep" side to create the visual information for a solid surface of support and a sheer drop-off (Figure 1A). The glass controlled for other potential sources of depth information (tactile, auditory, air currents, temperature, etc.) by equalizing the two sides. The centerboard was raised to preclude the rats from feeling the glass with their whiskers since they depend heavily on tactile cues for guiding locomotion. The procedure was simple: Rats were placed on the centerboard and could freely choose a side of the apparatus to explore.

The amazed researchers watched as both the light- and dark-reared animals descended from the centerboard to the shallow side; all but a handful rejected the deep side (Gibson, 1991; Walk, Gibson, & Tighe, 1957). The researchers quickly constructed a control condition to assure themselves that avoidance of the

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deep side was not due to some odor or sound cue in the room: With the patterned surface directly beneath both sides of the apparatus, rats descended with equal frequency to both sides.

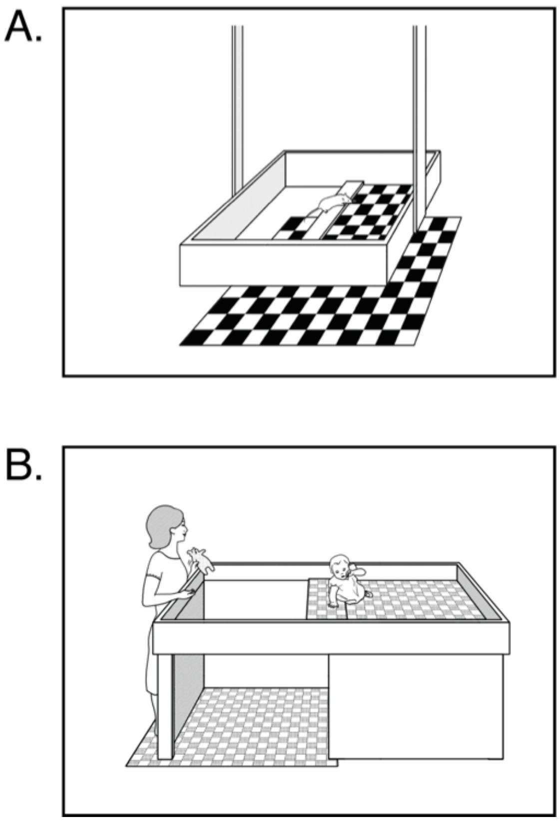

Figure 1. The visual cliff. (A) Original visual cliff constructed for testing rats and chicks. Researchers placed the animals on the centerboard and observed whether they descended to the shallow or deep side. (B) Modified visual cliff for testing larger animals and human infants. Animals were placed on the centerboard and allowed to descend to either side. Human infants were coaxed by their mothers to cross the deep and shallow sides on alternating trials.

Following their wild success with the rats, Gibson and Walk constructed larger and more elaborate versions of the visual cliff suitable for testing a wider variety of animals and human infants (Figure 1B). Like the adult hooded rats, land-living animals of many species and ages left the centerboard for the visually-specified surface of support and shunned the apparent drop-off (Reviewed in Gibson, 1969; Gibson & Walk, 1960; Walk, 1966, 1979; Walk & Gibson, 1961): Albino rats (with poor eyesight compared to hooded rats), infant rats, puppies, kittens, rabbit pups, chicks, adult chickens, infant ring doves (not precocial), kids, lambs, piglets, and infant rhesus monkeys descended to the shallow side. Adult chickens sometimes flew over the deep side, but always walked over the shallow side. Aquatic turtles largely preferred the shallow side, but showed the poorest discrimination of any species and were slowest to leave the centerboard. Infant ring doves had poor locomotor abilities, but hobbled toward the shallow side. However, the initial experiments with human infants (6- to 14-month olds) indicated that a different procedure was required because infants would not budge off the centerboard without their mothers serving as the lure. When mothers called to them from the shallow side, infants readily crossed, but on the deep side, most refused to go.

Impact of the Visual Cliff

The visual cliff has all the earmarks of a classic paradigm in science—robust and highly replicable findings; sensational and memorable images; and a simple yet elegant design. Perhaps most striking, the visual cliff has both common-sense appeal (everyone can understand the importance of avoiding locomotion over a large drop-off) and academic relevance: In addition to the question of whether visual experience is necessary for perceiving downward depth at an edge, developmental and comparative psychologists have used the visual cliff to study perceptual, motor, emotional, and social development (described below), visuomotor function after neurological injury or pharmacological intervention (e.g., Bourassa, Yajima, & Leonard, 1968; Campbell, 1978; Meyer, 1963; Walsh & Guralnick, 1971), and applied issues in animal care (Arnold, Ng, Jongman, & Hemsworth, 2007). In particular, the visual cliff—and the more general experimental procedure of placing infants in front of obstacles and observing their behavior—provided new avenues for understanding the role of experience in development.

Depth Perception

Based on their early findings, Gibson and Walk concluded that visual experience is not necessary for the development of depth discrimination (Walk, et al., 1957) and that animals are prepared to discriminate depth and avoid a drop-off as soon as they are independently mobile, even if locomotion begins at birth as in precocial chicks, kids, and lambs (Gibson & Walk, 1960). However, later studies revealed a more complicated story. Dark-reared rats avoided the deep side of the visual cliff upon emerging from the dark at 27 and 90 days, suggesting that perception of depth at an edge develops without visual experience. But at 140 or 300 days, depth discrimination was absent, suggesting that long-term deprivation caused permanent deficits (Nealey & Riley, 1964; Walk, Trychin, & Karmel, 1965).

For some species, the visual experience that comes with self-produced locomotion is necessary. Unlike rats, kittens dark-reared for 26 days showed no preference for the shallow side. But they caught up to their light-reared peers by the end of a week (Gibson & Walk, 1960; Walk, 1966; Walk & Gibson, 1961). Dark-reared kittens with 3 hours of daily exposure to light while actively locomoting in a "kitty carousel" acquired normal depth perception after 10 days of training (Held & Hein, 1963). They displayed visually guided "placing responses" (i.e., they extended their forepaws as they were slowly lowered toward a tabletop) and descended only to the shallow side of the visual cliff. In contrast, their yoked littermates who received only passive experience with movement-produced stimulation (by riding in a cart that was pulled by the active kitten) did not show normal placing responses and descended to both shallow and deep sides of the cliff indiscriminately. Moreover, normal experience moving around in the light does not guarantee immediate avoidance in altricial animals (those that are helpless at birth). Kittens and rabbit pups require about a month of locomotor experience in the light before showing consistent avoidance of the deep side (Walk, 1966; Walk & Gibson, 1961). Infant rhesus monkeys could be coaxed over the deep side before 2 weeks of age, but not a week or two later (Walk & Gibson, 1961). The cause of differences between altricial species such as rats and cats (e.g., dark-reared rats immediately avoid the deep side but dark-reared cats do not) remains unclear, but may depend on the animals' reliance on vision for guiding locomotion.

By varying the height of the drop-off, the existence of visible pattern, and the size of the checkerboard squares, the visual cliff can be used to estimate threshold sensitivity and to determine the information that specifies depth. Rats showed smooth psychometric functions, with increased avoidance of the deep side as the drop-off increased in 2-inch increments from 4 to 14 inches beneath the starting board (Walk & Gibson, 1961). Similarly, avoidance increased in human infants as the drop-off increased from 10 to 40 inches (Walk, 1966).

What information is used to specify the apparent drop-off? Visible texture is necessary. With textureless grey paper beneath both sides of the cliff, rats crossed indiscriminately (Walk & Gibson, 1961) and 32%-50% of human infants crossed the deep side regardless of whether the paper was 10 or 40 inches below the glass (Walk, 1966). Binocular disparity is not crucial. Monocular rats and chicks and infants wearing an eye patch avoided the deep side at the same rates as those that had both eyes available (Lore & Sawatski, 1969; Schiffman & Walk, 1963; Trychin & Walk, 1964; Walk, 1968b; Walk & Dodge, 1962). Motion parallax plays a stronger role in avoidance than texture density (Gibson & Walk, 1960; Walk, 1966; Walk & Gibson, 1961). With two different depths, the checks on the shallow side move more quickly across the retina than the checks on the deep side as the animal moves its head while peering over the edge (motion parallax). Additionally, under standard testing conditions with

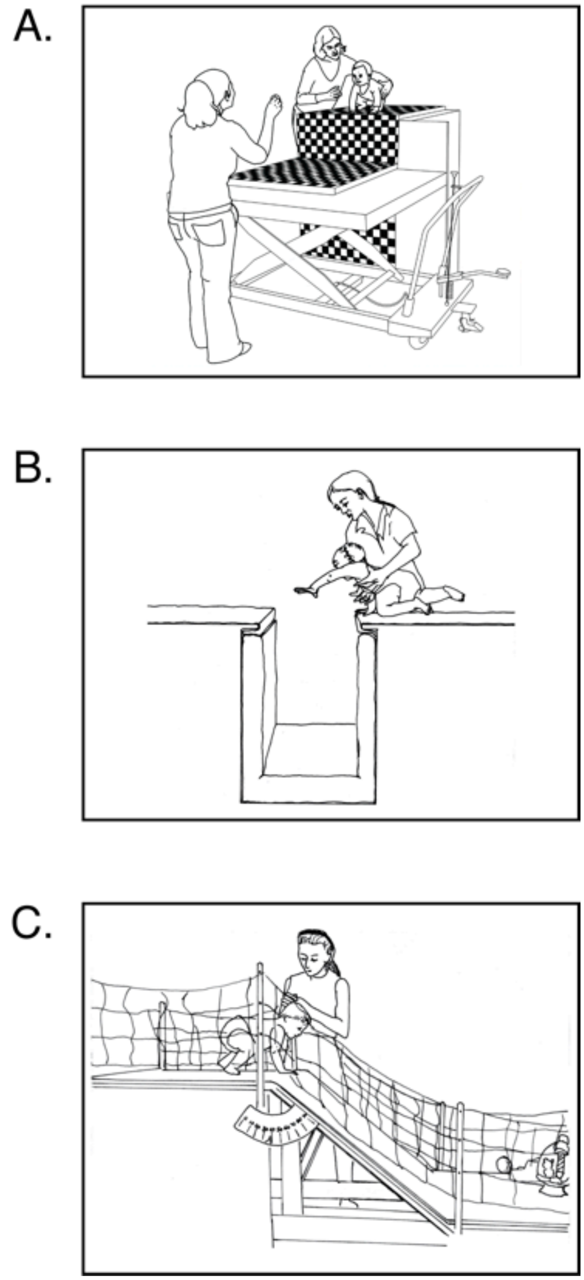

Figure 2. *Alternative paradigms for testing infants' perception of affordances with apparatuses that do not cover the drop-off with glass. (A) Adjustable drop-off apparatus (0 cm - 90 cm) used in Kretch and Adolph (2011) to present infants with real cliffs. (B) Adjustable gap apparatus (0 cm - 90 cm) used in Adolph (2000). (C). Adjustable slope apparatus (0° - 90°) used in Adolph (1997) and subsequent studies.*

identically sized checks on both sides, the pattern on the deep side presents a finer retinal texture and the pattern on the shallow side appears coarser (texture density). With distance held constant, rats preferred the side with a coarser texture, indicating that they can use texture density in the absence of differential motion parallax (Walk & Gibson, 1961). However, when the two sources of information were pitted against each other—the pattern on the deep side was so large that it appeared coarser despite its distance—rats and human infants showed a preference for the shallow side, indicating that motion parallax is the primary source of information when it is available (Gibson & Walk, 1960; Walk, 1966; Walk & Gibson, 1961).

A small flurry of comparative studies on depth perception followed (Davidson & Walk, 1969; DeHardt, 1969; Greenberg, 1986; Hansson, 1970; Morrison, 1982; O'Sullivan & Spear, 1964; Somervill, 1971; Somervill & Sharratt, 1970; Tallarico, 1962; Walk, 1968a; Walk & Walters, 1974), but use of the visual cliff as a means for studying depth perception in human infants was short-lived. As Gibson (1969) pointed out, many other behaviors develop earlier than locomotion (e.g., reaching and looking) and can be used to assess visual depth perception long before crawling onset (Yonas & Granrud, 1985). Indeed, looking time methods reveal that even newborns are sensitive to visual information for depth (Slater, Mattock, & Brown, 1990).

Perception of Affordances

In the 1980s, Gibson reconceptualized her studies with the visual cliff as investigations into the development of perception of "affordances"—the fit between an animal's physical capabilities and the features of the environment that allow a particular action to be performed (Gibson, 1988; Gibson & Schmuckler, 1989). Of course infants must perceive the disparity in depth to avoid the apparent drop-off, but other important factors are involved. Infants must also perceive that the drop-off is too high relative to their own body size and motor abilities and that their typical method of locomotion (crawling or walking) is impossible. In other words, they must perceive the affordances of the ground surface, the possibilities for action provided by available environmental supports.

This reconceptualization led to a series of studies on infants' perception of affordances for traversability (Gibson et al., 1987). Now Gibson's focus was on comparing crawling and walking infants because differences in the stability of their postures affect affordances for locomotion. Of special interest was the exploratory behaviors used to generate information for affordances. The general procedure was the same—infants began on a starting board facing a potential obstacle between themselves and their mothers—but in this case, the rigidity of the ground surface varied instead of the height of the drop-off. Crawling infants crossed a squishy waterbed more frequently than walking infants, but both groups went straight over rigid plywood. Walkers differentiated the two surfaces with increased visual and tactile exploration on the waterbed, whereas crawlers did not. In some experiments, the surfaces were covered in black velveteen to eliminate visible texture; now both crawlers and walkers crossed both surfaces, although feeling the waterbed ripple beneath them caused walkers to switch to crawling. When covered in glass to eliminate differential tactile information (an assistant agitated the waterbed from beneath to provide visual information for deformability), tactile information for the solid surface was more persuasive than visual information for inadequate support. Without the opportunity to feel the waterbed deform or to generate the visual information for rippling and deformability, both crawlers and walkers readily crossed.

Gibson's new view of the old visual cliff paradigm led to dozens of studies on infants' perception of affordances for locomotion: over real cliffs (Kretch & Adolph, 2011), gaps (Adolph, 2000; Adolph, Berger, & Leo, 2011; Zwart, Ledebt, Fong, de Vries, & Savelsbergh, 2005), slopes (e.g., Adolph, 1997), stairs (Ulrich, Thelen, & Niles, 1990), bridges (Berger & Adolph, 2003; Berger, Adolph, & Kavookjian, 2010; Berger, Adolph, & Lobo, 2005; Kretch, Kung, Quon, & Adolph, 2011), foam pits (Joh, 2011; Joh & Adolph, 2006), slippery ground (Adolph, Joh, & Eppler, 2010), under, over, and around barriers (Kingsnorth & Schmuckler, 2000; Lockman, 1984; Mulvey, Kubo, Chang, & Ulrich, 2011; Schmuckler, 1996; van der Meer, 1997), through apertures (Franchak & Adolph, 2011), and so on (Figure 2). Following Gibson's lead, most researchers examined the role of experience in adaptive responding, used human "spotters" to ensure infants' safety instead of glass to allow for multi-modal exploration, and observed infants' exploratory activity to understand the source of perceptual information for guiding behavior.

Like kittens and rabbits on the visual cliff, human infants require locomotor experience to respond adaptively to real cliffs and other real obstacles (for reviews, see Adolph & Berger, 2006, 2010). Prior falls outside the laboratory situation do not predict behavior (Adolph, 1997; Kretch & Adolph, 2011; Scarr & Salapatek, 1970; Walk, 1966). What seems to matter for human infants on real obstacles is the accumulation of experience from self-produced activity moving through the variety of surfaces in the everyday environment. Experience, however, does not transfer from earlier developing postures to later developing ones. Although infants spend months learning to control balance while sitting, this learning does not transfer to crawling (Adolph, 2000). Despite months of crawling and cruising, those experiences do not transfer to walking (Adolph, 1997; Adolph, et al., 2011; Adolph, Tamis-LeMonda, Ishak, Karasik, & Lobo, 2008; Kretch & Adolph, 2011). Learning to perceive affordances for locomotion is specific to each posture in development. Crawlers and walkers explore obstacles differently (e.g., crawlers probe ground surfaces with their hands, walkers with their feet), but in both postures exploratory activity becomes more efficient and refined. In addition, researchers have manipulated infants' bodies and skills to alter affordances. For example, experienced walkers perceive the altered affordances for walking down slopes while wearing lead-weighted vests that made them top-heavy or slippery, Teflon-soled shoes that put them off-balance (Adolph & Avolio, 2000; Adolph, Karasik, & Tamis-LeMonda, 2010).

Fear of Heights

From the beginning, Gibson and Walk considered the role of fear in cliff avoidance. Their monograph begins: "One of man's strongest fears is the fear of high places and falling" (Walk & Gibson, 1961, p. 1). But Gibson did not equate avoidance with fear and she did not believe that fear accompanied perception of affordances: "[Affordances] are not the attachment to a perception of feelings of pleasantness or unpleasantness. They are information for behavior that is of some potential utility to the animal… I doubt that a mountain goat peering over a steep crag is afraid or charged with any kind of emotion; he simply does not step off" (Gibson, 1982, p. 65).

On the visual cliff, animals were not afraid to approach and explore the deep side: Kids, lambs, rats, kittens, and puppies peered over the edge of the centerboard, touching their noses or whiskers to the glass if they could reach it, and human infants actively explored the glass on the deep side by patting it with their hands, leaning onto it, or laying their faces on it (Walk, 1966; Walk & Gibson, 1961). Later work confirmed infants' approach of the deep side and visual-tactile exploration of the glass (e.g., Ueno, Uchiyama, Campos, Dahl, & Anderson, 2011; Witherington, Campos, Anderson, Lejeune, & Seah, 2005). In fact, infants approach and explore the brink of real drop-offs (i.e., no glass covering the precipice) such as 50° slopes, 90-cm wide gaps, and 90-cm high cliffs (Adolph, 1997, 2000; Kretch & Adolph, 2011). To the extent that animals can see the drop-off and perceive the affordances, they simply avoid traversal or find an alternative means of descent (Gibson, 1982). In Gibson's view, fear of heights develops separately from perception of affordances: "Many people do become afraid of heights at some point, but this fear is probably learned long after motor patterns for responding appropriately to surfaces of support have developed" (Gibson, 1982, p. 65).

However, animals did show stereotyped fear reactions when they were placed directly onto the glass on the deep side or pushed over the edge of the precipice—a situation more akin to being thrown off a cliff rather than exploring the view from the edge. Kids, lambs, kittens, and puppies froze, trembled, and backed up, holding their front limbs rigid (Gibson & Walk, 1960; Walk & Gibson, 1961). Kids sometimes leaped over the chasm back to the centerboard and kittens turned in circles until feeling the restraining wall against their backs. One kitten climbed the restraining wall and clung to it. Monkeys lay prone hugging the glass or self-clasped and rocked (Rosenblum & Cross, 1963; Walk & Gibson, 1961). None of these animals walked forward on the deep side as they did when placed directly onto the shallow side (Walk & Gibson, 1961).

The placing procedure for animals inspired a similar placing procedure for human infants and more important, use of the visual cliff as a tool for studying the development of emotion in prelocomotor and crawling infants (Campos, Langer, & Krowitz, 1970). Unfortunately, despite a rash of studies focusing on measures of heart rate and facial expressions, the findings are equivocal. At 1.5 to 3.5 months of age, prelocomotor infants showed decelerated heart rate—an index of interest—after being placed prone on the deep side (Campos, et al., 1970). At 5 months, prelocomotor infants showed no change in heart rate (Schwartz, Campos, & Baisel, 1973). At 9 months, some researchers found accelerated heart rate—an index of fear—in crawling infants (Schwartz, et al., 1973) but others found decelerated heart rate (Richards & Rader, 1983). At 12 months, crawlers showed accelerated heart rate (Richards & Rader, 1983), but at 15 months, no differences (Schwartz, et al., 1973). Locomotor experience (either bona fide crawling or pushing around in a mechanical baby walker) predicted accelerated heart rate in some studies (Campos, Bertenthal, & Kermoian, 1992) but not others (Richards & Rader, 1983). In some cases, accelerated heart rate was accompanied by negative affect (Richards & Rader, 1983), but in others it was not (Campos, et al., 1992; Schwartz, et al., 1973), and sometimes infants displayed blends of fear, neutral, and other expressions (Hiatt, Campos, & Emde, 1979). Accelerated heart rate during placement sometimes predicted avoidance in the standard crawling procedure (Richards & Rader, 1983), but sometimes pounding hearts during placement were unrelated to avoidance (Ueno, et al., 2011). Facial expressions during the standard crossing procedure are also equivocal. Some researchers reported an increase of fearful expressions (Scarr & Salapatek, 1970) and some report neutral expressions (Sorce, Emde, Campos, & Klinnert, 1985) or smiles (Saarni, Campos, Camras, & Witherington, 2006). On the visual cliff, the strongest evidence for fear is avoidance of the drop-off, but using avoidance as evidence that fear mediates avoidance is circular.

In the waterbed/plywood situation, neither positive nor negative affect differentiated the two surfaces (Gibson, et al., 1987). In other paradigms, infants' affect was nearly uniformly positive or neutral, not negative. Their facial expressions and vocalizations were positive or neutral on more than 90% of trials on both safe and risky slopes while descending or refusing to descend and regardless of age and experience (Adolph, Karasik, et al., 2010; Adolph, et al., 2008; Tamis-LeMonda, Adolph, Lobo, Karasik, & Dimitropoulou, 2008).

Social Referencing

Non-human animals spontaneously explored the visual cliff apparatus on their own, but Gibson and Walk quickly realized that human infants would only leave the centerboard in the context of a social situation. In addition to visual information for depth, infants use social information from their mothers (Walk & Gibson, 1961). Infants also direct social communications to their mothers by holding out their arms toward them, pointing at the surface and looking at them, and vocalizing with apparent intent to communicate (Gibson, et al., 1987). In the early studies, mothers were instructed to stand at each side for 2 minutes twirling a pinwheel and silently smiling, but when infants refused to cross, they sometimes improvised by banging on the surface of the deep side and proffering cigarette boxes, lipsticks, purses, and crumpled bits of paper (Walk & Gibson, 1961). In the waterbed studies, mothers were instructed to smile silently for the first 30 seconds, encourage infants to come during the next 30 seconds, and failing that, to offer a key ring for 60 seconds as additional enticement (Gibson, et al., 1987).

Although Gibson and Walk did not systematically vary the valence of social information offered by caregivers, other researchers recognized the value of the visual cliff for studying developmental changes in infants' use of social information for guiding action. In fact, the visual cliff is the most famous paradigm for studying social referencing (Baldwin & Moses, 1996). In the best-known study, 12-month-olds crossed a 30 cm apparent drop-off (a height selected to be ambiguous) if their mothers silently posed static happy or interested facial expressions but not if mothers' faces were fearful or angry (Sorce, et al., 1985). With a shallow cliff, infants ignored their mothers' faces completely. However, subsequent studies failed to replicate the power of mothers' facial expressions to sway infants toward crossing or avoiding (Bradshaw, Goldsmith, & Campos, 1987; Vaish & Striano, 2004), suggesting that mere facial expressions may be insufficient as a source of social information. Crossing a 20- to 56-cm visual cliff was more likely in conditions where mothers spoke to infants while posing happy expressions than if offering only a positive facial expression or if mothers used adult directed speech (Striano, Vaish, & Benigno, 2006; Vaish & Striano, 2004).

Without the safety glass, social information can be pitted directly against the visual-tactile information infants generate from their own exploratory activity. On shallow slopes, for example, discouraging social information belies what infants see and feel for themselves and on steep slopes, encouraging social information conflicts with visual-tactile information. But on ambiguous slopes where the probability of successful descent is uncertain, social and perceptual information are on equal footing. Thus, if infants recognize the limits of their abilities and view their mothers as a potentially useful source of information, then they should defer to mothers' advice only on ambiguous increments. Using their full repertoire of motherly advice from a distance (dynamic facial expressions, vocal intonation and language, and hand and body gestures), mothers encouraged and discouraged their infants to descend individualized safe, ambiguous, and risky slopes (Adolph, Karasik, et al., 2010; Adolph, et al., 2008; Tamis-LeMonda, et al., 2008). Eighteen-month-olds deferred to mothers' advice only on ambiguous slopes: They walked when mothers said "go" but not when mothers said "no." On safe and risky slopes, they ignored the social information. When the point of ambiguity was experimentally decreased by fitting 18-month-olds with Teflon-soled shoes, infants updated selective use of social information to a shallower range of slopes. Selective use of social information develops: At 12 months of age, experienced crawlers responded to social information only at safe slopes, suggesting that they underestimated the extent of their own abilities; for same-aged novice walkers, social information affected behavior only on risky slopes, suggesting that they grossly overestimated their abilities.

A Critique of the Visual Cliff

Gibson and Walk were not the first to observe animals' responses to a cliff. Decades earlier, Lashley, Thorndike, Spaulding, Yerkes and others tested rats, chicks, pigs, and turtles at the edge of various types of drop-offs (described in Walk & Gibson, 1961). The innovation in the visual cliff paradigm was to make the drop-off illusory by covering the precipice with glass. The glass, however, also causes a variety of problems (recognized by Gibson and Walk), especially for testing human infants. In particular, the glass makes it difficult to assess the role of locomotor experience in adaptive responding.

Problems Due to Covering the Deep Side with Glass

The glass over the shallow side is not an issue, but the glass over the deep side results in conflicting visual and tactile information. In contrast to rats, for which the centerboard was eventually placed beyond reach of their whiskers, human infants can (and do) feel the glass. Thus, the surface looks completely insubstantial, but it feels solid and is perfectly safe for locomotion. Although kittens never seem to learn that fact, rats do: If they feel the glass, they cross the deep side (Walk & Gibson, 1961). And human infants do: Avoidance attenuates over repeated trials (Campos, Hiatt, Ramsay, Henderson, & Svejda, 1978; Eppler, Satterwhite, Wendt, & Bruce, 1997; Walk, 1966). Moreover, infants given experience playing with transparent boxes at home do not avoid the deep side when subsequently tested on the visual cliff (Titzer, 1995). As a consequence of within-session learning, the same infant cannot be tested repeatedly on the deep side, either to obtain multiple measurements within a session (e.g., at various drop-off heights) or across sessions longitudinally. Thus, visual cliff studies report a single trial per infant (or one deep and one shallow trial). The outcome is binary (avoid vs. cross) for each infant, rather than the proportion of trials on which each infant avoids, a more sensitive, continuous measure. By contrast, in studies using a human spotter instead of glass to ensure infants' safety, infants do not learn that the experimenter will catch them; infants show no evidence of within-session learning after dozens of trials, and they become more, not less, cautious over longitudinal testing (e.g., Adolph, 1997; Joh, 2011). Without the glass, it is possible to obtain psychometric functions for individual infants to determine each infant's skill level and the accuracy of their perception of affordances (Adolph & Berger, 2006).

When the aim is to study perception of affordances, infants' spontaneous search for multi-modal information is paramount (Gibson, et al., 1987). Infants can generate information by looking, touching, and testing different ways of navigating obstacles. Controlling for tactile cues and other non-visual sources of information—the raison d'etre for covering the cliff with glass—is largely moot. It reveals only how infants behave when visual and tactile information conflict, not how they behave normally when visual and tactile information are complementary or redundant. With any visible texture—a rippling waterbed or even sparse netting stretched beneath the glass—infants hesitate, but cross, suggesting that both visual and tactile information are important (Gibson, et al., 1987; Gibson & Schmuckler, 1989). Without the safety glass, infants explore the edge of a drop-off by stretching their arms down into the precipice or across the gap as if to measure the distance relative to their own body size and balance control, all the while looking at the obstacle and the goal and generating multimodal information (Adolph, 2000; Kretch & Adolph, 2011). Infants also explore a variety of alternative strategies for coping with obstacles. For example, they descend real cliffs by backing feet first or by scooting down in a sitting position (Kretch & Adolph, 2011). The glass precludes researchers from observing infants' discovery and use of such alternative means.

Moreover, the glass is forgiving of errors, whereas a real drop-off is not (Adolph, 2000; Adolph, et al., 2011; Kretch & Adolph, 2011; Walk & Gibson, 1961). On the visual cliff, infants inadvertently allow some or all of their body onto the deep side while trying to avoid it; they venture part way onto the glass toward their mothers and then retreat; and they lean their weight onto the safety glass while trying to explore it (Walk & Gibson, 1961). On a real cliff, they would have fallen. Similarly, when you read the fine print, rats scored as avoiding the deep end spend most of the trial exploring the shallow side of the visual cliff but they actually visit the deep side as well (Walk & Gibson, 1961). Thus, "avoidance" and "crossing" in visual cliff studies do not mean the same thing as in studies with real drop-offs. The former present a misleading positive picture of infants' ability to act adaptively at the edge of a drop-off. The latter hold infants to a much stricter criterion of adaptive responding.

Locomotor Experience

Although the visual cliff was well designed for studying dark-reared rats upon their first exposure to light, it has proven ill suited for studying effects of locomotor experience on the development of fear of heights and perception of affordances in human infants. As described above, researchers found discrepant outcomes for heart rate (acceleration, deceleration, and no change) and affect (negative, positive and neutral) during placement on the deep side and in infants who avoided the deep side. Effects for perception of affordances are equally discrepant. Some researchers found that age at crawling onset was a stronger predictor of avoidance on the deep side than days of crawling experience, with age at testing held constant—an explanation that favors maturation over experience (Rader, Bausano, & Richards, 1980; Richards & Rader, 1981, 1983). Moreover, precrawlers given a month of experience wheeling around in a mechanical baby walker or "crawligator" rolled over the deep side, again suggesting that locomotor experience per se is not critical (Rader, et al., 1980). Other researchers found that crawling experience was the strongest predictor of avoidance—an explanation that favors learning (Bertenthal & Campos, 1987, 1990; Bertenthal, Campos, & Barrett, 1984; Bertenthal, Campos, & Kermoian, 1994; Campos, et al., 1992; Campos, et al., 1978). Walk's (1966) early data were consistent with both explanations.

The visual cliff also yields discrepant data regarding the specificity of locomotor experience. For example, on the visual cliff, both 12-month-old experienced crawlers and 12-month-old novice walkers avoided the apparent drop-off, suggesting that locomotor experience transfers from crawling to walking (Witherington, et al., 2005). In fact, novice walkers avoided the deep side more than experienced crawlers. However, in other studies, crawling infants were reticent to cross the deep side when tested in a crawling posture, but the same infants were equally quick to cross both sides when tested upright in a mechanical baby walker (Rader, et al., 1980).

Perhaps problems arising from the use of glass on the deep side can explain the discrepant findings regarding the role of locomotor experience. On a real cliff, 12-month-old experienced crawlers consistently refused to crawl over drop-offs beyond their ability whereas 12-month-old novice walkers repeatedly marched over the edge (Kretch & Adolph, 2011). The crawlers showed smooth psychometric functions with decreasing attempts scaled to their own level of crawling skill, rarely erring even on cliffs 1 to 3 cm beyond their ability. The walkers attempted to walk (and fell) on 75% of trials at cliffs 9 cm beyond their abilities and on 50% of trials on a 90-cm cliff—comparable to the deep side of the visual cliff.

Conclusions: Beyond the Visual Cliff

For psychologists, the visual cliff has retained its reputation as a landmark paradigm. It is a mainstay in every introductory textbook on psychology, development, and perception. The images of infants or animals standing on a checkerboard surface peering over the edge of a cliff are among the iconography of the field. For Walk, the visual cliff remained a primary research paradigm in his laboratory and a source of fascination throughout his career (Walk, 1979), although he went on to study a variety of other topics in perceptual learning and development (Pick & Tighe, 2001). For Gibson (trained in perception, learning, and comparative psychology), the visual cliff inspired more general questions about perception of affordances and perceptual learning and opened up a whole new world of developmental inquiry (Gibson, 1969, 1991). (Prior to her studies using the visual cliff, Gibson had never studied human infants and did not even know how to recruit them). Even in her 70s and 80s, Gibson continued to study perceptual-motor learning and development (the waterbed studies were published when she was 77 years old) and to mentor students (Adolph, Eppler, & Gibson, 1993; Gibson, 1997). She immensely enjoyed watching the growth of research on perception of traversability in infants and adults. As she put it, the real questions do not concern exactly what transfers as infants acquire locomotor experience, or even the perceptual information that specifies affordances, but how flexibility of behavior is achieved (Gibson, 1997). That is, how does any animal learn what it takes to respond adaptively while moving through the world from moment to moment and task to task? Such learning must require much more than exposure to instinctive elicitors, forming associative links between stimuli, or altering responses based on feedback from errors because the knowledge obtained is creative and generative and immensely flexible. Flexibility of behavior requires "learning to learn" to perceive and exploit affordances adaptively.

What would Gibson say regarding the remaining puzzles inspired by the visual cliff paradigm in areas of perception, motor skill acquisition, emotional development, and social referencing? Her advice to students was always to run another experiment.

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