3 Infants on the Edge

Beyond the Visual Cliff

Karen E. Adolph, Brianna E. Kaplan, & Kari S. Kretch

One of the most iconic images in developmental psychology is an infant peering over the edge of an illusory drop-off on the "visual cliff" (Figure 1A). The apparatus, created by Eleanor Gibson and Richard Walk in the late 1950s, is a glass platform divided by a centerboard into a large, cliff-sized drop-off on one side and a tiny, step-sized drop-off on the other. The glass is carefully lighted to be invisible (hence the "visual" in visual cliff). Infants must decide whether to leave the centerboard to reach their caregiver who beckons from the "deep" or "shallow" side. The paradigm has such commonsense appeal, face validity, and potential import for understanding psychological functions—surely, every reader recognizes the danger of falling over a precipice—that infants' behavior on the visual cliff appears in lay magazines (e.g., *Scientific American*) and top academic journals (e.g., *Science*) and is a classic finding in psychology textbooks.

THE BACKSTORY

Eleanor Gibson amused her students and family with stories about the inspiration for the visual cliff (also described in Gibson, 1991, 2002; Rodkey, 2015; Walk, 1979). According to student and family lore, the first seed was planted during a family road trip to the Grand Canyon in the mid-1940s. Gibson worried that her two young children playing near the rim might fall into the canyon, although her husband, perception psychologist James Gibson, assured her that the children were sensitive to the visual information for depth. A second source of inspiration was Gibson's experience with animals that avoid a drop-off shortly after birth. While preparing newborn goats for an experiment at the Cornell Behavior Farm circa 1950, Gibson 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 calmly stood upright on the tiny pedestal until she finished birthing and washing the second twin. A third possible source of inspiration was Walk's experience with army recruits at Fort Benning in the early 1950s. The soldiers practiced parachute jumps from a high tower and many were afraid of heights.

Regardless, the direct impetus for the visual cliff paradigm was the practical exigencies of a difficult rearing experiment. In the 1950s, rearing animals under altered environmental conditions was a popular method to assess the role of experience in development. Accordingly, Gibson and Walk had nearly completed the grueling process of dark-rearing rats for a study of visual form discrimination. Gibson hoped to capitalize on their efforts by running the animals in a second study. Remembering the Grand Canyon and goat anecdotes or perhaps inspired by the army recruits, they thought of depth discrimination (Gibson, 1991; Walk, 1979). Visual depth perception in dark-reared rats seemed an appropriate way to address the age-old question of whether perception of space requires visual experience. But how to test it? Lashley and Russell's (1934) famous experiments with dark-reared rats on a jumping stand required two days in the light to train the animals to use the apparatus. 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. Rather than calibrating the force to jump from one stand to another, the rats would need only to decide whether to walk over the edge. The experiment required a new apparatus that could pit visual information for a drop-off against visual information for solid ground while controlling for other sources of information for safe descent. And so, the visual cliff was born.

THE VISUAL CLIFF

The first (rat-sized) visual cliff apparatus was jerry-rigged by Thomas Tighe (then Gibson and Walk's doctoral research assistant) with objects found around the lab—pieces of glass, wood, rods, clamps, and patterned wallpaper (or linoleum tiles or a checkered tablecloth, depending on Gibson's telling of the story). A 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 to create the visual information for a solid surface of support and far below the glass on the "deep" side to simulate a sheer drop-off (Figure 1B). Of course, the glass beneath the centerboard ensured rats' safety (as would a net), but more critically, the glass ensured that only visual information distinguished the two sides. The glass equalized other potential sources of relevant information (tactile cues from touching the glass, auditory cues from ambient noise in the room, air currents, temperature, etc.) across the two sides. The centerboard was raised (7.6-cm high) to preclude the animals from immediately feeling the glass with their whiskers. The procedure was simple. Rats were placed on the centerboard and could freely choose whether to descend to one side or the other.

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 deep side was not due to some odor or sound cue in the room. With the patterned surface directly beneath the glass on both sides of the apparatus, rats descended with equal frequency to both sides. Moreover, with the visually-specified drop-off eliminated, the control animals explored back and forth, often crossing the centerboard to the other side several times.

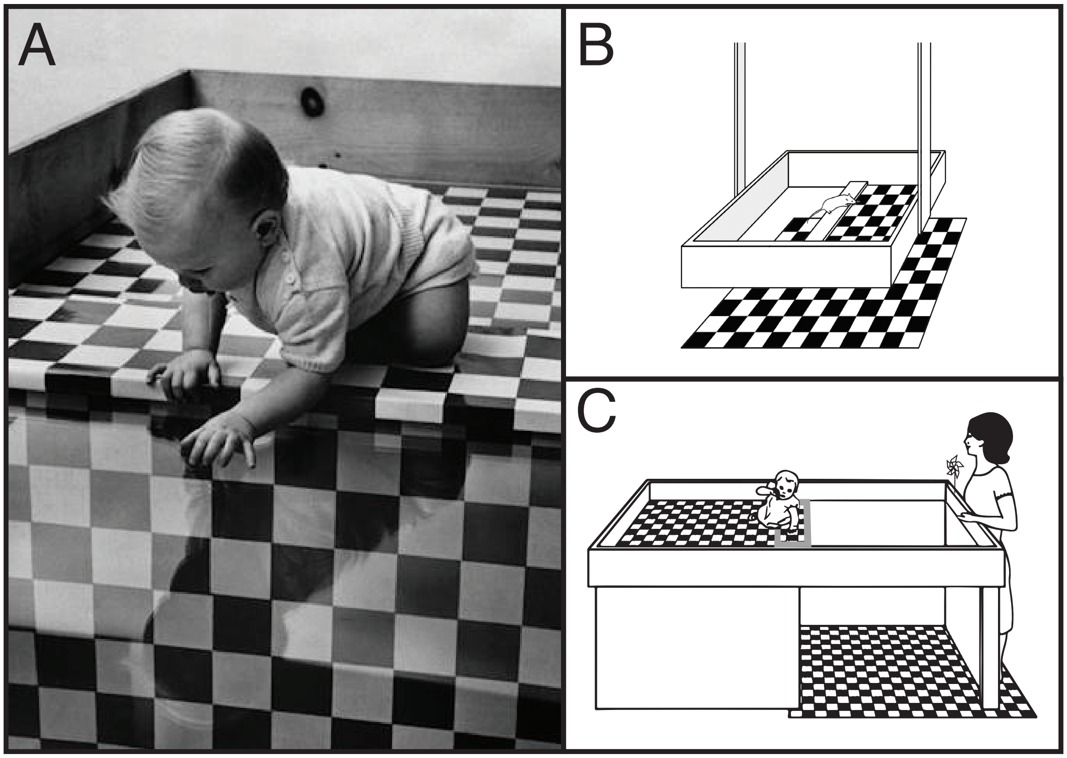

Figure 3.1 The visual cliff. (A) Iconic photo of an infant peering over the visual cliff. Republished with permission of Taylor & Francis Group LLC-Books, from *Perceiving the Affordances: A Portrait of Two Psychologists*, Eleanor J. Gibson, 2001; permission conveyed through Copyright Clearance Center, Inc. (B) Original visual cliff constructed for testing rats and chicks. Researchers placed the animals on the raised centerboard and observed whether they descended to the shallow or deep side. (C) Modified visual cliff for testing larger animals and human infants. Grey outline denotes the centerboard. 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 adult hooded rats, Gibson and Walk quickly realized that many types of animals could be tested at the edge of the illusory drop-off at various stages of learning and development. So, they constructed larger and more elaborate versions of the visual cliff suitable for testing a wider variety of animals and human infants (Figure 1C). Like the adult hooded rats, land-living animals of many species and ages left the centerboard for the visually-specified surface of support and avoided going over the apparent drop-off (reviewed in Gibson, 1969, 1970; Gibson &

Walk, 1960; Walk, 1966, 1979; Walk & Gibson, 1961). Adult albino rats (with poor eyesight compared to hooded rats) descended to the shallow side. So did rat pups, rabbit pups, chicks, ducklings, ring dove squabs, land turtles, tortoises, puppies, cats (including lions, tigers, jaguars, and snow leopards), piglets, lambs, kids, infant rhesus monkeys, and other rodents (e.g. Israeli gerbils, California voles, house mice) at various ages (Patterson, 1971; Routtenberg & Glickman, 1964; Sloane, Shea, Procter, & Dewsburth, 1978; Walk, 1966, 1972; Walk & Gibson, 1961). Infant ring doves had poor locomotor abilities but hobbled toward the shallow side. Adult chickens sometimes flew over the deep side, but they almost 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 (Walk & Gibson, 1961). Only three types of animals, all rodents (white-footed mice, prairie voles, and montane voles), did not avoid the deep side (Sloane et al., 1978). Experiments with human infants (6- to 14-month-old crawling babies) required a different procedure because infants would not budge off the centerboard without their mothers serving as the lure (Gibson & Walk, 1960). When mothers called to them from the shallow side, infants readily crossed, but when they beckoned from the deep side, most infants refused to go.

Gibson and Walk published their first findings from the dark-reared rats on the visual cliff in 1957 in *Science*. On its heels came their 1960 *Scientific American* article with the famous photographs of infants and kittens on a checkerboard surface perched on the brink of the apparent precipice. Their most scholarly work, the 1961 piece in *Psychological Monographs*, described their comparative studies.

IMPACT OF THE VISUAL CLIFF

The visual cliff has all the earmarks of a classic scientific paradigm—robust and replicable findings; sensational and memorable images; and a simple yet elegant design. Perhaps most important, the visual cliff is widely applicable to a slew of research questions and thus generated off-shoot paradigms and new areas of research (as of this writing, Google Scholar lists about 5000 articles referencing the visual cliff).

In addition to the question of whether visual experience is necessary to perceive depth at an edge, comparative psychologists and neuroscientists use the visual cliff to study visuomotor and behavioral function after neurological injury or pharmacological intervention (Basha & Radha, 2017; Bourassa, Yajima, & Leonard, 1968; Campbell, 1978; Meyer, 1963; Walsh & Guralnick, 1971; Zhang et al., 2017), applied issues in animal care (Arnold, Ng, Jongman, & Hemsworth, 2007), and perceptual, motor, emotional, and social development in human infants (described below). In particular, the visual cliff—and the more general experimental procedure of observing how infants navigate obstacles—provided new avenues for understanding links between perception and action and the importance of visual and locomotor experience in development.

DEPTH PERCEPTION: INFORMATION FOR THE DROP-OFF

Adult rats are highly sensitive to the differences in depth of the apparent drop-off. Estimates of threshold sensitivity showed smooth psychometric functions, with increased avoidance of the deep side as the drop-off increased in 5.1-cm increments from 10.2 to 35.6 cm beneath the starting board (Walk & Gibson, 1961). Note we converted inches (the standard metric in older papers) to centimeters to allow easier comparisons.

Thus, Gibson and Walk manipulated aspects of the cliff to determine what visual information animals use to discriminate depth. Visible texture is necessary. With smooth grey paper on each side, rats crossed indiscriminately (Walk & Gibson, 1961). Similarly, 41% of human infants crossed the deep side when the textureless paper was 101.6 cm below the glass (Walk, 1966). In contrast, binocular disparity (i.e., disparities in visual angle between the two eyes) is not necessary. Monocular rats and chicks and human 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).

Both texture density and motion parallax are important cues for depth. Under standard testing conditions with identically sized checks on both sides, texture density varies because the checks on the shallow side are visually larger (i.e., larger on the retina) and create a coarser retinal texture than the checks on the deep side. With large checks directly beneath the glass on one side and small checks directly beneath the glass on the other, rats preferred the side with the coarser texture, indicating they can use texture density in the absence of differential motion parallax (Walk & Gibson, 1961). In the standard arrangement, the different depths create motion parallax as the animal moves its head while peering over the edge (i.e., the visually larger checks on the shallow side move more quickly across the retina than the visually smaller checks on the deep side). With checks on the deep side enlarged and spaced apart to eliminate differences in texture density, rats still preferred the shallow side (Gibson & Walk, 1960; Walk & Gibson, 1961). However, when the two sources of information were pitted against each other—density cues favored the deep side (checks enlarged beyond the retinal size on the shallow side) and motion parallax cues favored the shallow side (checks moved faster on the retina)—rats and human infants preferred the shallow side, indicating that motion parallax is the primary source of information when it is available (Walk, 1966; Walk & Gibson, 1961).

Based on their early findings, Gibson and Walk concluded that visual experience is not needed for the development of depth discrimination (Walk et al., 1957) and that animals 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 or 90 days, suggesting that depth perception develops without visual experience. But after 140 or 300 days in the dark, depth discrimination was initially absent (Nealey & Riley, 1964; Walk, Trychin, & Karmel, 1965).

Moreover, for some species, the visual experience that comes with self-produced locomotion is necessary to discriminate depth at an edge. Unlike rats, kittens dark-reared for a month showed no initial preference for the shallow side. But they caught up to their light-reared peers by the end of a week in the light (Gibson & Walk, 1960; Walk, 1966; Walk & Gibson, 1961). Dark-reared kittens given 3 hours of daily light exposure during active locomotion for 10 days acquired normal depth perception and only descended to the shallow side. However, their yoked littermates who received only passive experience with movement-produced visual stimulation descended to the shallow and deep sides of the cliff indiscriminately (Held & Hein, 1963). Moreover, normal experience moving around in the light does not guarantee immediate avoidance in altricial animals (those that cannot locomote at birth). Kittens and rabbit pups require about a month of experience walking around in the light before showing consistent avoidance of the deep side (Walk, 1966). 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 among altricial species such as rats and cats is unclear, but may depend on the animals' reliance on vision for guiding locomotion.

Like kittens and rabbit pups, human infants are altricial, but unlike kittens and rabbits, age at onset of locomotion varies widely. Infants acquire independent mobility—typically crawling—at 6 to 11 months of age (Martorell et al., 2006). Thus, age at crawling onset, age at testing, and days of crawling experience covary. Unfortunately, the visual cliff yields discrepant findings about the importance of these variables. Some researchers found that older 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, some researchers found that precrawlers given a month of experience wheeling around upright in a mechanical baby walker or prone in a "crawligator" rolled themselves over the deep side (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, Bertenthal, & Kermoian, 1992; Campos, Hiatt, Ramsay, Henderson, & Svejda, 1978). Walk's (1966) early data were consistent with both maturation- and experience-based explanations.

The visual cliff also yields discrepant data regarding the specificity of locomotor experience. In some studies, 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, Campos, Anderson, Lejeune, & Seah, 2005). However, in other studies, crawling infants avoided the deep side when tested in a crawling posture, but the same babies were equally quick to cross both sides when tested upright in a mechanical baby walker (Rader et al., 1980).

A flurry of studies compared depth perception in a variety of animals (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 using avoidance on the deep side of the visual cliff to study depth perception in human infants was short-lived. As Gibson (1969) herself pointed out, other behaviors develop earlier than locomotion (e.g., reaching and looking) that can be used to assess visual depth perception long before crawling onset (Yonas & Granrud, 1985). Indeed, looking-time methods revealed that newborns are sensitive to visual information for depth (Slater, Mattock, & Brown, 1990). And prelocomotor infants showed decelerated heartrate when placed face-down on the deep but not the shallow side of the visual cliff (Campos, Langer, & Krowitz, 1970).

PERCEPTION OF AFFORDANCES FOR LOCOMOTION ON REAL OBSTACLES

Gibson also pointed out that avoidance at the edge of a precipice requires more than depth perception. It requires animals to perceive affordances—and lack of them—for locomotion (Gibson, 1988; Gibson & Schmuckler, 1989). An "affordance" is the fit between the animal and environment that makes a particular action possible (Adolph & Kretch, 2015). A drop-off, for example, is only a "cliff" relative to a particular animal's body and skills. The deep side of the rat cliff is merely a shallow "step" to an adult goat. Indeed, that's why Gibson built rat- and goat-sized cliffs. Of course, animals must perceive the disparity in depth to avoid the apparent drop-off, but other important factors are also involved. Animals must 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, walking, slithering, etc.) is impossible.

In the 1980s, Gibson devised new apparatuses to test human infants' perception of affordances for locomotion. The general procedure was the same—infants began on a starting board facing an obstacle between themselves and their caregivers—but in this case, the rigidity of the ground surface varied instead of the height of the drop-off (Gibson et al., 1987). Crawling infants crossed a squishy waterbed more frequently than did walking infants, but both groups went straight over a rigid plywood surface. The two groups also differed in the exploratory behaviors used to generate information for affordances. Walkers increased their visual and haptic exploration on the waterbed, whereas crawlers did not. When the surfaces were covered in black velveteen to eliminate visible texture, both crawlers and walkers ventured onto both surfaces. When covered in glass to eliminate differential haptic information (the waterbed rippled to provide visual information for deformability), haptic information for the solid glass was more persuasive than visual information for inadequate support; without the opportunity to feel the waterbed deform, both crawlers and walkers readily crossed. Similarly, later research showed that visual information is insufficient to guide navigation over surfaces varying in rigidity or friction. Without prior haptic exploration, walking infants fell repeatedly into a visually distinct, deformable "foam pit" and likewise on a white, shiny, slippery Teflon slope (Figure 2A-B). However, after touching the squishy or slippery surface, infants rarely attempted to walk (Adolph, Joh, & Eppler, 2010; Joh & Adolph, 2006).

Gibson's work inspired dozens of studies on human infants' perception of affordances for locomotion (Figure 2). In addition to surfaces varying in rigidity and friction, apparatuses include an array of potential obstacles—drop-offs, slopes, gaps, bridges, ledges, apertures, overhead and underfoot barriers, and so on. And rather than an apparent drop-off, infants are tested at the edge of an actual drop-off, where the penalty for errors is falling into the precipice (instead of safety glass, an experimenter follows alongside infants to catch them with their hands or a harness if infants fall). In many cases, the obstacles are adjustable (e.g., drop-off heights varying in 1-cm increments from 0-90 cm, slopes varying in 2° increments from 0-90°, bridge widths varying in 2-cm increments from 2-70 cm).

With real obstacles (no safety glass), every published study shows that human infants require self-produced locomotor experience to respond adaptively (for reviews, see Adolph & Berger, 2006; Adolph & Hoch, 2019; Adolph & Robinson, 2015). In their first weeks of sitting, crawling, cruising, and walking, infants plunged headlong over the brink of a real precipice, but over weeks of experience, their decisions became increasingly accurate. Experienced infants perceived affordances with centimeter precision when challenged with balance and locomotion at the brink of real cliffs (Karasik, Tamis-LeMonda, & Adolph, 2016; Kretch & Adolph, 2013a), a "water cliff" where the starting platform abuts a deep pool of water (Burnay & Cordovil, 2016), slopes (e.g., Adolph, 1997; Adolph, Eppler, & Gibson, 1993), gaps (Adolph, 2000; Zwart, Ledebt, Fong, de Vries, & Savelsbergh, 2005), bridges (Berger & Adolph, 2003; Berger, Adolph, & Kavookjian, 2010; Berger, Adolph, & Lobo, 2005; Kretch & Adolph, 2013b, 2017), and ledges (Franchak & Adolph, 2012); Figure 2C-H. However, when navigating through apertures (Franchak & Adolph, 2012), under or over barriers (Kingsnorth & Schmuckler, 2000; Mulvey, Kubo, Chang, & Ulrich, 2011; Schmuckler, 1996; van der Meer, 1997), or up slopes (Adolph, 1993, 1995, 1997), infants were less accurate, likely because the perceived penalty of entrapment or falling on uphill slopes or on flat ground is less salient than falling downward into a precipice (Figure 2I). Indeed, infants precisely perceived affordances for inching along narrow ledges but erred when deciding whether they could squeeze through narrow apertures (Franchak & Adolph, 2012). In some studies, researchers manipulated infants' bodies and skills to alter the body-environment fit (Figure 2J-K). For example, experienced walkers perceived the altered affordances for walking down slopes while wearing lead-weighted shoulder-packs or Teflon-soled shoes (Adolph & Avolio, 2000; Adolph, Karasik, & Tamis-LeMonda, 2010). Prior falls outside the laboratory situation and experience with particular obstacles do not predict behavior (Adolph, 1997; Kretch & Adolph, 2013a). What seems to matter is accumulated experience from self-produced activity moving on a variety of surfaces in the everyday environment.

On real obstacles, experience does not transfer from earlier developing postures to later developing ones. Although infants spend months learning to control balance while sitting, their learning does not transfer to crawling (Adolph, 2000). Despite months of crawling and cruising, infants' experiences do not transfer to walking (Adolph, 1997; Adolph, Berger, & Leo, 2011; Adolph, Tamis-LeMonda, Ishak, Karasik, & Lobo, 2008; Karasik et al., 2016; Kretch & Adolph, 2013a). Apparently, learning to perceive affordances for locomotion is specific to each posture in development. For example, 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 stepped over the edge (Kretch & Adolph, 2013a). Crawlers showed smooth psychometric functions with decreasing attempts scaled to their own level of crawling skill, rarely erring even on cliffs 1-3 cm beyond their ability. 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 drop-off—comparable to the deep side of the visual cliff. Although crawlers and walkers explore obstacles differently (e.g., crawlers probe ground surfaces with their hands, walkers with their feet), in both postures exploratory activity becomes more efficient and refined.

What might infants learn from locomotor experience? One idea is that experienced infants make use of peripheral lamellar optic flow, which supports visual proprioception (Dahl et al., 2013; Ueno et al., 2018). Presumably, the lack of optic flow at the edge of a 90-cm drop-off conflicts with vestibular information and creates a sense of height vertigo that leads to avoidance. However, this explanation does not account for infants' ability to discriminate possible from impossible actions with centimeter precision, for infants' ability to update their assessments of affordances based on trial-to-trial changes in their bodies and skills, or for lack of transfer between earlier and later developing postures. An alternative explanation is that infants learn to perform exploratory behaviors that generate useful information about varying body-environment relations and thus to detect which actions are possible and which are not (Adolph & Berger, 2006; Adolph & Hoch, 2019; Adolph & Robinson, 2015).

FEAR OR WARINESS OF HEIGHTS?

Perhaps the most popular notion of what infants learn via everyday locomotor experience is that infants acquire fear or wariness of heights. Indeed, 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).

Although the term "avoidance" suggests that animals shied away from the brink, they did not (Adolph, Kretch, & LoBue, 2014; LoBue & Adolph, 2019). In Gibson's original studies, 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' proximity to the deep side and visual-tactile exploration of the glass (e.g., Ueno, Uchiyama, Campos, Dahl, & Anderson, 2012; Witherington et al., 2005). In fact, infants approached and explored the brink of real drop-offs such as 90-cm high cliffs, 50° slopes, and 90-cm wide gaps (Adolph, 1997, 2000; Adolph et al., 2008; Kretch & Adolph, 2013a).

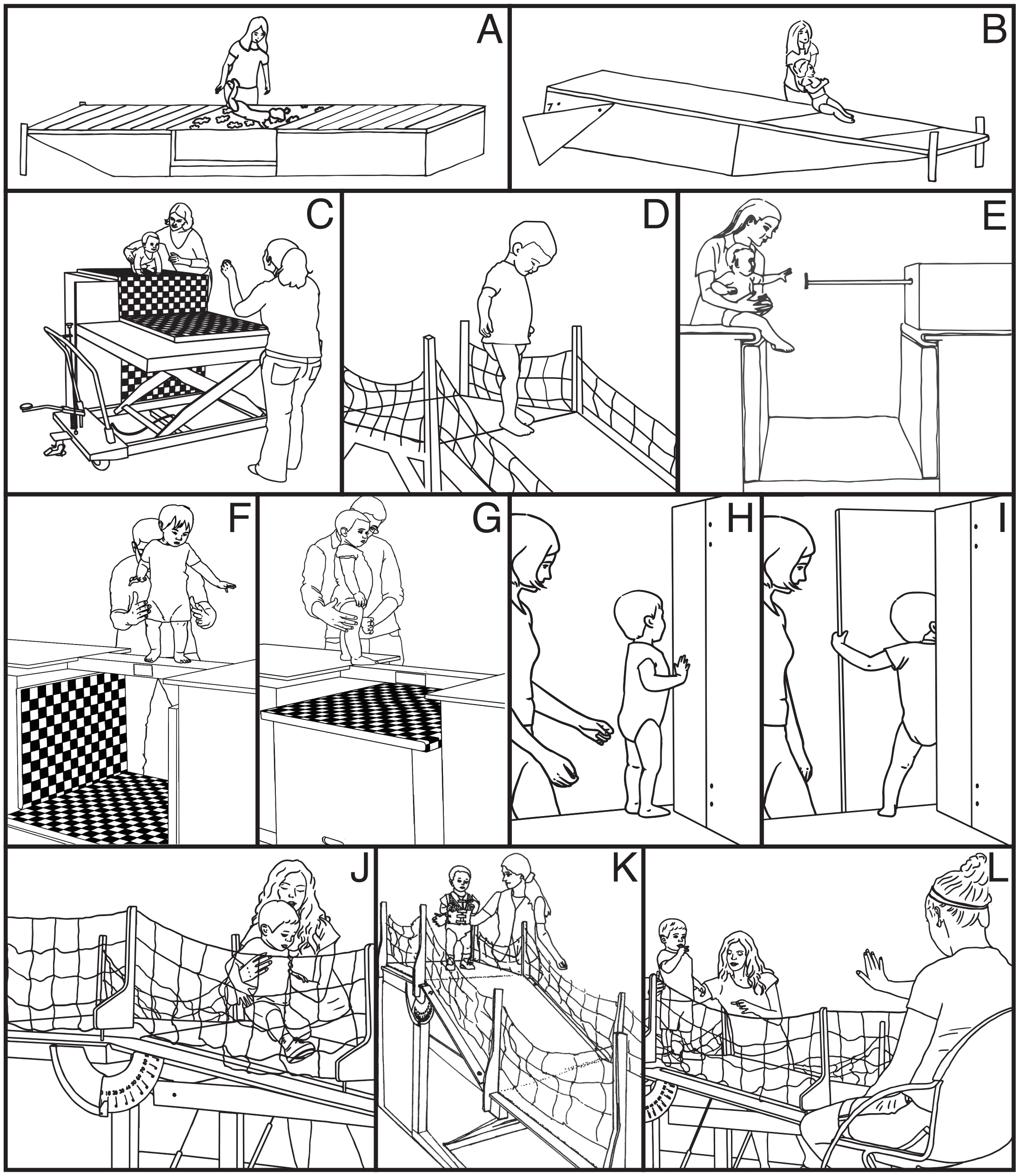

Figure 3.2 Paradigms to test infants' perception of affordances without safety glass. (A) Walking infant falling into the foam pit used in Joh and Adolph (2006). (B) Walking infant sliding on the slippery Teflon surface used in Adolph, Joh, et al. (2010). (C) Crawling infant approaching the adjustable drop-off (0-90 cm) used in Kretch and Adolph (2013a). (D) Walking infant negotiating the adjustable slope (0°-50°) used in Adolph (1997) and subsequent studies. (E) Sitting infant at the edge of the adjustable gap (0-90 cm) used in Adolph (2000). (F-G) Walking infant approaching the adjustable bridge (2-60 cm) spanning a large 77-cm drop-off and a small 17-cm drop-off used in Kretch and Adolph (2013b). (H-I) Walking infant negotiating the adjustable ledge (0-70 cm) and squeezing through the adjustable aperture (0-70 cm) used in Franchak and Adolph (2012). (J) Walking infant wearing slippery Teflon-soled shoes sliding down the slope used in Adolph, Karasik, et al. (2010). (K) Walking infant wearing lead-weighted shoulder-packs at the top of the adjustable slope (0-40°) used in Adolph and Avolio (2000). (L) Walking infant deciding whether to walk down an adjustable (0°-50°) slope as the caregiver discourages descent as in (Adolph, Karasik, et al., 2010), Adolph et al. (2008), and Tamis-LeMonda et al. (2008).

In addition, infants' behaviors when crossing narrow bridges above a small drop-off (17 cm) or a large drop-off (71 cm) were indistinguishable (Figure 2F-G). Infants based their crossing decisions and gait modifications only on bridge width, not on the severity of a potential fall (Kretch & Adolph, 2013b). Apparently, to the extent that animals can see the drop-off and perceive the affordances, they avoid traversal or find an alternative means of descent. But they do not avoid proximity to the brink. 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, in Gibson's original work, 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 (Gibson & Walk, 1960; Walk & Gibson, 1961). Kids, lambs, kittens, and puppies froze, trembled, and backed up, holding their front limbs rigid. 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).

The placing procedure for animals inspired a similar placing procedure for human infants and more important, use of the visual cliff as a tool to study the development of emotion in prelocomotor and crawling infants (Campos et al., 1970). Unfortunately, measures of heart rate and facial expressions yield equivocal findings. At 1.5 to 3.5 months of age, prelocomotor infants showed decelerated heart rate—an index of interest—when 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 arousal or 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, pushing around in a mechanical baby walker, or driving a powered baby go-cart) predicted accelerated heart rate in some studies (Campos et al., 1992; Dahl et al., 2013) 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., 2012).

Facial expressions are also equivocal in the standard crossing procedure. On the visual cliff, some researchers reported an increase of fearful expressions (Scarr & Salapatek, 1970) and some reported neutral expressions (Sorce, Emde, Campos, & Klinnert, 1985) or smiles (Saarni, Campos, Camras, & Witherington, 2006). In the waterbed/plywood paradigm, neither positive nor negative affect differentiated the two surfaces (Gibson et al., 1987). On real drop-offs, infants' affect was nearly always positive or neutral. Infants' 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 et al., 2008). On the visual cliff or any other apparatus with a drop-off, the strongest evidence that fear, wariness, or any negative emotion mediates avoidance is avoidance itself, and thus the argument is circular (Adolph et al., 2014; LoBue & Adolph, 2019).

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 when deciding whether to cross the deep side (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 to study developmental changes in infants' use of social information for guiding action. In fact, the visual cliff is the most famous paradigm to study 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). Researchers found no difference in how fast and with how much anxiety infants crossed the cliff when encouraged by mothers versus fathers (Moller, Majdandzic, & Bogels, 2014).

Without the safety glass, social information can be pitted directly against the visual-tactile information infants generate from their own exploratory activity. Using their full repertoire of motherly advice from a distance (dynamic facial expressions, vocal intonation and language, and hand and body gestures as shown in Figure 2L), mothers encouraged and discouraged their infants to descend safe, ambiguous, and risky slopes and drop-offs (Adolph et al., 2008; Karasik et al., 2016; Tamis-LeMonda et al., 2008). Experienced 18-month-old walkers deferred to mothers' advice only on ambiguous increments: They walked when mothers said "go" but not when mothers said "no." But on safe and risky increments, infants ignored the social information and relied instead on what they could see and feel for themselves. When the point of ambiguity was experimentally decreased by fitting 18-month-olds with Teflon-soled shoes, infants shifted their use of social information to a shallower range of slopes (Adolph, Karasik, et al., 2010). Selective use of social information develops: At 12 months of age, experienced crawlers responded to social information only at safe or ambiguous slopes and drop-offs; for same-aged novice walkers, social information affected behavior only on ambiguous or risky increments (Adolph et al., 2008).

A CRITIQUE OF THE VISUAL CLIFF

Gibson and Walk were not the first to observe animals' behavior at the edge of a drop-off. 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 was to make the drop-off illusory by covering the precipice with glass. The glass and other structural aspects of the standard cliff, however, also cause a variety of problems, especially for testing human infants (Adolph & Berger, 2006).

PROBLEMS DUE TO COVERING THE DEEP SIDE WITH GLASS

The glass makes the deep side perfectly safe for locomotion and thus precludes repeated testing. Kittens never seem to learn that locomotion is possible, but rats do: With the glass placed within reach of their whiskers, rats crossed the deep side (Walk & Gibson, 1961). Similarly, human infants feel the glass and avoidance attenuates over repeated trials (Campos et al., 1978; Eppler, Satterwhite, Wendt, & Bruce, 1997; Walk, 1966). As a consequence, 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 deep trial per infant. The outcome is binary (avoid vs. cross), rather than the proportion of trials on which each infant avoids, a more sensitive, continuous measure. In 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 (e.g., Adolph, 2000; Adolph et al., 2011), and they become more, not less, cautious over weeks of longitudinal testing (e.g., Adolph, 1997). 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 (e.g., Kretch & Adolph, 2013a).

The glass over the deep side presents conflicting visual and tactile information and thus precludes observations of how infants obtain information for affordances. When the aim is to study perception of affordances, infants' spontaneous search for multimodal information is paramount (Gibson et al., 1987). Controlling for tactile cues and other non-visual sources of information—the raison d'être 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 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 hesitated, but crossed, suggesting that both visual and tactile information are important (Gibson et al., 1987; Gibson & Schmuckler, 1989). Without the safety glass, infants explored the edge of a drop-off by stretching their arms down into the precipice or across the gap, rocking over their ankles at the brink of a slope, or putting their toes onto the edge of a bridge, as if to measure the dimensions relative to their own body size and balance control, all the while looking at the obstacle and the goal and generating multimodal information (Adolph, 1997, 2000; Kretch & Adolph, 2013a, 2013b). Infants also explored a variety of alternative strategies for coping with obstacles. For example, they descended real cliffs by backing down feet first or by scooting down in a sitting position (Karasik et al., 2016; Kretch & Adolph, 2013a). The glass precludes researchers from observing infants' discovery and use of such alternative means.

Moreover, the glass is forgiving of errors and thus leads researchers to over-credit infants' perception of affordances. But a real drop-off does not (Adolph, 2000; Karasik et al., 2016; Kretch & Adolph, 2013a, 2013b). On the visual cliff, infants inadvertently put some or all of their body onto the deep side while trying to avoid it; they ventured part way onto the glass toward their mothers and then retreated; and they leaned their weight onto the safety glass while trying to explore it (Walk & Gibson, 1961). Even if infants intended to avoid the deep side, their exploratory behavior would have led to a fall without the safety glass. Some infants held onto the side wall of the cliff and creeped along the edge of the deep side to their caregivers (Witherington et al., 2005). Again, on a real cliff, infants would have fallen. Therefore, the visual cliff may measure infants' (and other animals') intent, not their behavior. Perhaps after feeling the empty space on a real cliff, infants would not have continued dangerous exploratory behaviors, but we cannot know. More generally, "avoidance" and "crossing" in visual cliff studies do not mean the same thing as in studies with real drop-offs. The former presents a misleading positive picture of infants' ability to act adaptively at the edge of a drop-off. The latter holds infants to a much stricter criterion of adaptive responding.

STRUCTURAL PROBLEMS WITH THE APPARATUS

Several other structural problems make the visual cliff ill-suited for testing human infants. The dimensions worked fine for rats on the original cliff (Figure 1B), but when the cliff scaled up for larger animals and babies, the problems scaled up with it. First, as shown in Figure 1A and 1C, the centerboard is too narrow (29.2 cm front to back) to comfortably fit infants' bodies. Placing infants sitting or prone on the narrow centerboard gave them no room to decide whether to approach the brink and no room to shift postures or find alternative methods of locomotion without inadvertently shifting their weight off the board. This problem persisted in Gibson's (1987) waterbed/plywood studies and may explain why so many walkers crawled rather than walked over the surfaces. In contrast, a larger starting platform (90-274.3 cm long as shown in Figure 2) allows researchers to record infants' behavior as they see the obstacle from a distance—a situation more akin to negotiating cluttered terrain in everyday life. For example, head-mounted eye tracking shows that only a brief glance of the obstacle from the periphery is sufficient to induce experienced walkers to decrease their step length as they approach the brink and to prompt them to engage in exploratory touching at the edge of the precipice (Kretch & Adolph, 2017).

Second, the wide dimensions of the visual cliff (182.9 cm from side to side) precluded researchers from placing infants on the middle of the centerboard. The infants had to be placed near the edge of the apparatus, and in many studies, the caregiver stood diagonally to the infant rather than at the middle of the deep or shallow side (e.g., Witherington et al., 2005). Third, the wood walls supported the glass and ensured that infants could not crawl over the edge, but the walls gave infants something visible and tangible to hang onto as they made their way to the caregiver on the deep side (e.g., Witherington et al., 2005). In contrast, apparatuses 76-97 cm wide allow researchers to place infants in the middle of the starting platform, and to spot infants as they decide whether and how to traverse the obstacle (Figure 2). In summary, the overly narrow centerboard, overly wide apparatus, and wooden walls make it difficult for researchers to obtain converging behavioral measures.

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 studied 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 after her "retirement" when Gibson was in her 70s and 80s, she continued to study perceptual-motor learning and development (the waterbed studies were published when she was 77 years old) and to mentor students (Adolph et al., 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.

ACKNOWLEDGMENTS

This work was supported by National Institute of Health and Human Development Grants R37-HD33486 and R01-HD33486 to Karen E. Adolph. We gratefully acknowledge family and friends who offered their memories about the origins of the visual cliff paradigm: Peter Gordon, Jackie’s family (Jerry and Lois Gibson and Jean Rosenberg), and several of Jackie’s students (Lorraine Bahrick, Marion Eppler, Anne Pick, Herb Pick, Mark Schmuckler, Elizabeth Spelke, Tom Stoffregen, and Al Yonas).

FURTHER READING

Adolph, K. E., & Robinson, S. R. (2015). Motor development. In L. Liben & U. Muller (Eds.), *Handbook of child psychology and developmental science* (7th ed., Vol. 2 Cognitive Processes, pp. 113-157). New York: Wiley.

Bertenthal, B. I., Campos, J. J., & Barrett, K. C. (1984). Self-produced locomotion: An organizer of emotional, cognitive, and social development in infancy. In R. N. Emde & R. J. Harmon (Eds), *Continuities and discontinuities in development* (pp. 175–210). New York: Plenum Press.

Gibson, E. J., & Schmuckler, M. A. (1989). Going somewhere: An ecological and experimental approach to development of mobility. *Ecological Psychology, 1*, 3–25.

Gibson, E. J., & Walk, R. D. (1960). The “visual cliff”. *Scientific American, 202*, 64–71.

Kretch, K. S., & Adolph, K. E. (2013). Cliff or step? Posture-specific learning at the edge of a drop-off. *Child Development, 84*, 226-240.

REFERENCES

Adolph, K. E. (1993). Development of perception of affordances. In C. K. Rovee-Collier & L. P. Lipsitt (Eds.), *Advances in infancy research* (Vol. 8, pp. 51-98). Norwood, NJ: Ablex.

Adolph, K. E. (1995). Psychophysical assessment of toddlers' ability to cope with slopes. *Journal of Experimental Psychology: Human Perception and Performance, 21*, 734-750.

Adolph, K. E. (1997). Learning in the development of infant locomotion. *Monographs of the Society for Research in Child Development, 62*(3, Serial No. 251), 1-140.

Adolph, K. E. (2000). Specificity of learning: Why infants fall over a veritable cliff. *Psychological Science, 11*, 290-295.

Adolph, K. E., & Avolio, A. M. (2000). Walking infants adapt locomotion to changing body dimensions. *Journal of Experimental Psychology: Human Perception and Performance, 26*, 1148-1166.

Adolph, K. E., & Berger, S. E. (2006). Motor development. In D. Kuhn & R. S. Siegler (Eds.), *Handbook of child psychology* (6th ed., Vol. 2 Cognitive Processes, pp. 161-213). New York: Wiley.

Adolph, K. E., Berger, S. E., & Leo, A. J. (2011). Developmental continuity? Crawling, cruising, and walking. *Developmental Science, 14*, 306-318.

Adolph, K. E., Eppler, M. A., & Gibson, E. J. (1993). Crawling versus walking infants' perception of affordances for locomotion over sloping surfaces. *Child Development, 64*, 1158-1174.

Adolph, K. E., & Hoch, J. E. (2019). Motor development: Embodied, embedded, enculturated, and enabling. *Annual Review of Psychology, 70*, 141-164.

Adolph, K. E., Joh, A. S., & Eppler, M. A. (2010). Infants' perception of affordances of slopes under high and low friction conditions. *Journal of Experimental Psychology: Human Perception and Performance, 36*, 797-811.

Adolph, K. E., Karasik, L. B., & Tamis-LeMonda, C. S. (2010). Using social information to guide action: Infants' locomotion over slippery slopes. *Neural networks, 23*, 1033-1042.

Adolph, K. E., & Kretch, K. S. (2015). Gibson's theory of perceptual learning. In H. Keller (Ed.), *International encyclopedia of the social and behavioral sciences* (2nd ed., Vol. 10, pp. 127-134). New York: Elsevier.

Adolph, K. E., Kretch, K. S., & LoBue, V. (2014). Fear of heights in infants? *Current Directions in Psychological Science, 23*, 60-66.

Adolph, K. E., & Robinson, S. R. (2015). Motor development. In L. Liben & U. Muller (Eds.), *Handbook of child psychology and developmental science* (7th ed., Vol. 2 Cognitive Processes, pp. 113-157). New York: Wiley.

Adolph, K. E., Tamis-LeMonda, C. S., Ishak, S., Karasik, L. B., & Lobo, S. A. (2008). Locomotor experience and use of social information are posture specific. *Developmental Psychology, 44*, 1705-1714.

Arnold, N. A., Ng, K. T., Jongman, E. C., & Hemsworth, P. H. (2007). Responses of dairy heifers to the visual cliff formed by a herringbone milking pit: Evidence for fear of heights in cows (*Bos taurus*). *Journal of Comparative Psychology, 121*, 440-446.

Baldwin, D. A., & Moses, L. J. (1996). The ontogeny of social information gathering. *Child Development, 67*, 1915-1939.

Basha, P. M., & Radha, M. J. (2017). Gestational di-n-butyl phthalate exposure induced developmental and teratogenic anomalies in rats: A multigenerational assessment. *Environmental Science of Pollution Research, 24*, 4537-4551.

Berger, S. E., & Adolph, K. E. (2003). Infants use handrails as tools in a locomotor task. *Developmental Psychology, 39*, 594-605.

Berger, S. E., Adolph, K. E., & Kavookjian, A. E. (2010). Bridging the gap: Solving spatial means-ends relations in a locomotor task. *Child Development, 81*, 1367-1375.

Berger, S. E., Adolph, K. E., & Lobo, S. A. (2005). Out of the toolbox: Toddlers differentiate wobbly and wooden handrails. *Child Development, 76*, 1294-1307.

Bertenthal, B. I., & Campos, J. J. (1987). New directions in the study of early experience. *Child Development, 58*, 560-567.

Bertenthal, B. I., & Campos, J. J. (1990). A systems approach to the organizing effects of self-produced locomotion during infancy. In C. K. Rovee-Collier & L. P. Lipsitt (Eds.), *Advances in infancy research* (Vol. 6, pp. 1-60). Norwood, NJ: Ablex.

Bertenthal, B. I., Campos, J. J., & Barrett, K. C. (1984). Self-produced locomotion: An organizer of emotional, cognitive, and social development in infancy. In R. N. Emde & R. J. Harmon (Eds.), *Continuities and discontinuities in development* (pp. 175-210). New York: Plenum Press.

Bertenthal, B. I., Campos, J. J., & Kermoian, R. (1994). An epigenetic perspective on the development of self-produced locomotion and its consequences. *Current Directions in Psychological Science, 3*, 140-145.

Bourassa, C. M., Yajima, K., & Leonard, H. A. (1968). Effects of partial and total cerebellar ablations on visual cliff performance in the hooded rat. *Journal of Comparative and Physiological Psychology, 65*, 167-169.

Bradshaw, K. D. L., Goldsmith, H. H., & Campos, J. J. (1987). Attachment, temperament, and social referencing: Interrelationships among three domains of infant affective behavior. *Infant Behavior and Development, 10*, 223-231.

Burnay, C., & Cordovil, R. (2016). Crawling experience predicts avoidance of real cliffs and water cliffs: Insight from a new paradigm. *Infancy, 21*, 677-684.

Campbell, A. (1978). Deficits in visual learning produced by posterior temporal lesions in cats. *Journal of Comparative and Physiological Psychology, 92*, 45-57.

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

Campos, J. J., Hiatt, S., Ramsay, D., Henderson, C., & Svejda, M. (1978). The emergence of fear on the visual cliff. In M. Lewis & L. Rosenblum (Eds.), *The development of affect* (pp. 149-182). New York: Plenum.

Campos, J. J., Langer, A., & Krowitz, A. (1970). Cardiac responses on the visual cliff. *Science, 170*, 196-197.

Dahl, A., Campos, J. J., Anderson, D. I., Uchiyama, I., Witherington, D. C., Ueno, M., . . . Barbu-Roth, M. (2013). The epigenesis of wariness of heights. *Psychological Science, 24*, 1361-1367.

Davidson, P. W., & Walk, R. D. (1969). Differential visual depth discrimination of hooded as compared to albino rats. *Psychonomic Science, 14*, 207-208.

DeHardt, D. C. (1969). Visual cliff behavior of rats as a function of pattern size. *Psychonomic Science, 15*, 268-269.

Eppler, M. A., Satterwhite, T., Wendt, J., & Bruce, K. (1997). Infants' responses to a visual cliff and other ground surfaces. In M. A. Schmuckler & J. M. Kennedy (Eds.), *Studies in Perception and Action IV* (pp. 219-222). Mahway, NJ: Lawrence Erlbaum Associates.

Franchak, J. M., & Adolph, K. E. (2012). What infants know and what they do: Perceiving possibilities for walking through openings. *Developmental Psychology, 48*, 1254-1261.

Gibson, E. J. (1969). *Principles of perceptual learning and development*. New York: Appleton-Century Crofts.

Gibson, E. J. (1970). The development of perception as an adaptive process. *American Scientist, 58*, 98-107.

Gibson, E. J. (1982). The concept of affordances in development: The renascence of functionalism. In W. A. Collins (Ed.), *The concept of development: The Minnesota Symposia on Child Psychology* (Vol. 15, pp. 55-81). NJ: Lawrence Erlbaum Associates.

Gibson, E. J. (1988). Exploratory behavior in the development of perceiving, acting, and the acquiring of knowledge. *Annual Review of Psychology, 39*, 1-41.

Gibson, E. J. (1991). *An odyssey in learning and perception*. Cambridge, MA: MIT Press.

Gibson, E. J. (1997). Discovering the affordances of surfaces of support. *Monographs of the Society for Research in Child Development, 62*(3, Serial No. 251), 159-162.

Gibson, E. J. (2002). *Perceiving the affordances: A portrait of two psychologists*. Mahwah, NJ: Lawrence Erlbaum Associates.

Gibson, E. J., Riccio, G., Schmuckler, M. A., Stoffregen, T. A., Rosenberg, D., & Taormina, J. (1987). Detection of the traversability of surfaces by crawling and walking infants. *Journal of Experimental Psychology: Human Perception and Performance, 13*, 533-544.

Gibson, E. J., & Schmuckler, M. A. (1989). Going somewhere: An ecological and experimental approach to development of mobility. *Ecological Psychology, 1*, 3-25.

Gibson, E. J., & Walk, R. D. (1960). The "visual cliff". *Scientific American, 202*, 64-71.
Greenberg, G. (1986). Depth perception on Mongolian gerbils (*Meriones unguiculatus*) and spiny mice (*Acomys russatus* and *A. cahirinus*). *Journal of Comparative Psychology, 100*, 81-84.

Hansson, S. B. (1970). Visual depth discrimination in young eiders (*somateria mollissima*). *Psychological Research Bulletin, 10*, 16.

Held, R., & Hein, A. (1963). Movement-produced stimulation in the development of visually guided behavior. *Journal of Comparative and Physiological Psychology, 56*, 872-876.

Hiatt, S. W., Campos, J. J., & Emde, R. N. (1979). Facial patterning and infant emotional expression: Happiness, surprise, and fear. *Child Development, 50*, 1020-1035.

Joh, A. S., & Adolph, K. E. (2006). Learning from falling. *Child Development, 77*, 89-102.

Karasik, L. B., Tamis-LeMonda, C. S., & Adolph, K. E. (2016). Decisions at the brink: Locomotor experience affects infants' use of social information on an adjustable drop-off. *Frontiers in Psychology, 7*, 797.

Kingsnorth, S., & Schmuckler, M. A. (2000). Walking skill versus walking experience as a predictor of barrier crossing in toddlers. *Infant Behavior and Development, 23*, 331-350.

Kretch, K. S., & Adolph, K. E. (2013a). Cliff or step? Posture-specific learning at the edge of a drop-off. *Child Development, 84*, 226-240.

Kretch, K. S., & Adolph, K. E. (2013b). No bridge too high: Infants decide whether to cross based on the probability of falling not the severity of the potential fall. *Developmental Science, 16*, 336-351.

Kretch, K. S., & Adolph, K. E. (2017). The organization of exploratory behaviors in infant locomotor planning. *Developmental Science, 20*, e12421.

Lashley, K. S., & Russell, J. T. (1934). The mechanism of vision. XI. A preliminary test of innate organization. *Journal of Genetic Psychology, 45*, 136-144.

LoBue, V., & Adolph, K. E. (2019). Fear in infancy: Lessons from snakes, spiders, heights, and strangers. *Developmental Psychology, 55*, 1889-1907.

Lore, R., & Sawatski, D. (1969). Performance of binocular and monocular infant rats on the visual cliff. *Journal of Comparative and Physiological Psychology, 67*, 177-181.

Martorell, R., Onis, M., Martines, J., Black, M., Onyango, A., & Dewey, K. G. (2006). WHO motor development study: Windows of achievement for six gross motor development milestones. *Acta Paediatrica, 95 (S450)*, 86-95.

Meyer, P. M. (1963). Analysis of visual behavior in cats with extensive neocortical ablations. *Journal of Comparative and Physiological Psychology, 56*, 397-401.

Moller, E. L., Majdandzic, M., & Bogels, S. M. (2014). Fathers' versus mothers' social referencing signals in relation to infant anxiety and avoidance: A visual cliff experiment. *Developmental Science, 17*, 1012-1028.

Morrison, P. R. (1982). Distance cues and depth avoidance on the visual cliff. *Perceptual and Motor Skills, 54*, 1195-1198.

Mulvey, G. M., Kubo, M., Chang, C. L., & Ulrich, B. D. (2011). New walkers with Down Syndrome use cautious but effective strategies for crossing obstacles. *Research Quarterly for Exercise and Sport, 82*, 210-219.

Nealey, S. M., & Riley, D. A. (1964). Loss and recovery of discrimination of visual depth in dark-reared rats. *The American Journal of Psychology, 76*, 329-332.

O'Sullivan, D. J., & Spear, N. E. (1964). Comparison of hooded and albino rats on the visual cliff. *Psychonomic Science*, 87-88.

Patterson, R. (1971). Visual cliff perception in tortoises. *Herpetologica, 27*, 339-341.
Pick, H. L., & Tighe, T. J. (2001). Obituary: Richard D. Walk (1920-1999). *American Psychologist, 56*, 1169.

Rader, N., Bausano, M., & Richards, J. E. (1980). On the nature of the visual-cliff-avoidance response in human infants. *Child Development, 51*, 61-68.

Richards, J. E., & Rader, N. (1981). Crawling-onset age predicts visual cliff avoidance in infants. *Journal of Experimental Psychology: Human Perception and Performance, 7*, 382-387.

Richards, J. E., & Rader, N. (1983). Affective, behavioral, and avoidance responses on the visual cliff: Effects of crawling onset age, crawling experience, and testing age. *Psychophysiology, 20*, 633-642.

Rodkey, E. N. (2015). The visual cliff's forgotten menagerie: Rats, goats, babies, and myth-making in the history of psychology. *Journal of the History of the Behavioral Sciences, 51*, 113-140.

Rosenblum, L. A., & Cross, H. A. (1963). Performance of neonatal monkeys in the visual cliff situation. *American Journal of Psychology, 76*, 318-320.

Routtenberg, A., & Glickman, S. E. (1964). Visual cliff behavior in undomesticated rodents, land and aquatic turtles, and cats (panthera). *Journal of Comparative and Physiological Psychology, 58*, 143-146.

Saarni, C., Campos, J. J., Camras, L. A., & Witherington, D. (2006). Emotional development: Action, communication, and understanding. In N. Einsenberg (Ed.), *Handbook of child psychology. Vol. 3. Social, emotional, and personality development* (6th ed., pp. 226-299). New York: John Wiley & Sons.

Scarr, S., & Salapatek, P. (1970). Patterns of fear development during infancy. *Merrill-Palmer Quarterly, 16*, 53-90.

Schiffman, H. R., & Walk, R. D. (1963). Behavior on the visual cliff of monocular as compared with binocular chicks. *Journal of Comparative and Physiological*

Psychology(6), 1064-1068.

Schmuckler, M. A. (1996). Development of visually guided locomotion: Barrier crossing by toddlers. *Ecological Psychology, 8*, 209-236.

Schwartz, A. N., Campos, J. J., & Baisel, E. J. (1973). The visual cliff: Cardiac and behavioral responses on the deep and shallow sides at five and nine months of age. *Journal of Experimental Child Psychology, 15*, 86-99.

Slater, A., Mattock, A., & Brown, E. (1990). Size constancy at birth: Newborn infants' responses to retinal and real size. *Journal of Experimental Child Psychology, 49*, 314-322.

Sloane, S. A., Shea, S. L., Procter, M. M., & Dewsburth, D. A. (1978). Visual cliff performance in 10 species of muroid rodents. *Animal Learning and Behavior, 6*, 244-248.

Somervill, J. W. (1971). Motion parallax in the visual cliff situation. *Perceptual and Motor Skills, 32*, 43-53.

Somervill, J. W., & Sharratt, S. (1970). Retinal size in the visual cliff situation. *Perceptual and Motor Skills, 31*, 903-911.

Sorce, J. F., Emde, R. N., Campos, J. J., & Klinnert, M. D. (1985). Maternal emotional signaling: Its effects on the visual cliff behavior of 1-year-olds. *Developmental Psychology, 21*, 195-200.

Striano, T., Vaish, A., & Benigno, J. P. (2006). The meaning of infants' looks: Information seeking and comfort seeking? *British Journal of Developmental Psychology, 24*, 615-630.

Tallarico, R. B. (1962). Studies of visual depth perception: IV. comparisons of texture densities on a visual cliff by chicks. *Perceptual and Motor Skills, 15*, 626.

Tamis-LeMonda, C. S., Adolph, K. E., Lobo, S. A., Karasik, L. B., Dimitropoulou, K. A., & Ishak, S. (2008). When infants take mothers' advice: 18-month-olds integrate perceptual and social information to guide motor action. *Developmental Psychology, 44*, 734-746.

Trychin, S., & Walk, R. D. (1964). A study of the depth perception of monocular hooded rats on the visual cliff. *Psychonomic Science, 1*, 53-54.

Ueno, M., Uchiyama, I., Campos, J. J., Anderson, D. I., He, M., & Dahl, A. (2018). Crawling experience relates to postural and emotional reactions to optic flow in a virtual moving room. *Journal of Motor Learning and Development, 6*(Suppl 1), S63-S75.

Ueno, M., Uchiyama, I., Campos, J. J., Dahl, A., & Anderson, D. I. (2012). The organization of wariness of heights in experienced crawlers. *Infancy, 17*, 376-392.

Vaish, A., & Striano, T. (2004). Is visual reference necessary? Contributions of facial versus vocal cues in 12-month-olds' social referencing behavior. *Developmental Science, 7*, 261-269.

van der Meer, A. L. H. (1997). Visual guidance of passing under a barrier. *Early Development and Parenting, 6*, 149-157.

Walk, R. D. (1966). The development of depth perception in animals and human infants. *Monographs of the Society for Research in Child Development, 31*(5, Serial No. 107).

Walk, R. D. (1968a). The influence of level of illumination and size of pattern on the depth perception of the kitten and the puppy. *Psychonomic Science, 12*, 199-200.

Walk, R. D. (1968b). Monocular compared to binocular depth perception in human infants. *Science, 162*, 473-475.

Walk, R. D. (1972). Visual depth preferences of the domestic duckling. *Journal of Comparative and Physiological Psychology, 78*, 14-21.

Walk, R. D. (1979). Depth perception and a laughing heaven. In A. D. Pick (Ed.), *Perception and its development: A tribute to Eleanor J. Gibson* (pp. 63-88). Hillsdale, NJ: Erlbaum.

Walk, R. D., & Dodge, S. H. (1962). Visual depth perception of a 10-month-old monocular human infant. *Science, 137*, 529-530.

Walk, R. D., & Gibson, E. J. (1961). A comparative and analytical study of visual depth perception. *Psychological Monographs, 75*(15, Whole No. 519).

Walk, R. D., Gibson, E. J., & Tighe, T. J. (1957). Behavior of light- and dark-reared rats on a visual cliff. *Science, 126*, 80-81.

Walk, R. D., Trychin, S., & Karmel, B. Z. (1965). Depth perception in the dark-reared rat as a function of time in the dark. *Psychonomic Science, 3*, 9-10.

Walk, R. D., & Walters, C. P. (1974). Importance of texture-density preferences and motion parallax for visual depth discrimination by rats and chicks. *Journal of Comparative and Physiological Psychology, 86*, 309-315.

Walsh, J. M., & Guralnick, M. J. (1971). The effects of epinephrine and chlorpromazine on visual cliff behavior in hooded and albino rats. *Psychonomic Science, 23*, 1-3.

Witherington, D. C., Campos, J. J., Anderson, D. I., Lejeune, L., & Seah, E. (2005). Avoidance of heights on the visual cliff in newly walking infants. *Infancy, 7*, 285-298.

Yonas, A., & Granrud, C. E. (1985). Reaching as a measure of infants' spatial perception. In G. Gottlieb & N. A. Krasnegor (Eds.), *Measurement of audition and vision in the first year of postnatal life* (pp. 301-322). Norwood, NJ: Ablex.

Zhang, D., Wang, X., Wang, B., Garza, J. C., Fang, X., Wang, J., . . . Lu, X. Y. (2017). Adponectin regulates contextual fear extinction and intrinsic excitability of dentate gyrus granule neurons through AdipoR2 receptors *Molecular Psychiatry, 22*, 1044-1055.

Zwart, R., Ledebt, A., Fong, B. F., de Vries, H., & Savelsbergh, G. J. P. (2005). The affordance of gap crossing in toddlers. *Infant Behavior and Development, 28*, 145-154.