

The "Visual Cliff"
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*This simple apparatus is used to investigate depth perception in different animals.
All species thus far tested seem able to perceive and avoid a sharp drop as soon
as they can move about.*

Human infants at the creeping and toddling stage are notoriously prone to falls from more or less high places. They must be kept from going over the brink by side panels on their cribs, gates on stairways and the vigilance of adults. As their muscular coordination matures they begin to avoid such accidents on their own. Common sense might suggest that the child learns to recognize falling-off places by experience—that is, by falling and hurting himself. But is experience really the teacher? Or is the ability to perceive and avoid a brink part of the child's original endowment?



Answers to these questions will throw light on the genesis of space perception in general. Height perception is a special case of distance perception: information in the light reaching the eye provides stimuli that can be utilized for the discrimination both of depth and of receding distance on the level. At what stage of development can an animal respond effectively to these stimuli? Does the onset of such response vary with animals of different species and habitats?

At Cornell University we have been investigating these problems by means of a simple experimental setup that we call a visual cliff. The cliff is a simulated one and hence makes it possible not only to control the optical and other stimuli (auditory and tactual, for instance) but also to protect the experimental subjects. It consists of a board laid across a large sheet of heavy glass which is supported a foot or more above the floor. On one side of the board a sheet of patterned material is placed flush against the undersurface of the glass, giving the glass the appearance as well as the substance of solidity. On the other side a sheet of the same material is laid upon the floor; this side of the board thus becomes the visual cliff (Fig. 1).

FIGURE 1

The Classic Visual Cliff Experiment

This young explorer has the good sense not to crawl out onto an apparently unsupported surface, even when Mother beckons from the other side. Rats, pups, kittens, and chicks also will not try to walk across to the other side. (So don't bother asking why the chicken crossed the visual cliff.)

We tested 36 infants ranging in age from six months to 14 months on the visual cliff. Each child was placed upon the centre board, and his mother called him to her from the cliff side and the shallow side successively. All of the 27 infants who moved off the board crawled out on the shallow side at least once; only three of them crept off the brink onto the glass suspended above the pattern on the floor. Many of the infants crawled away from the mother when she called to them from the cliff side; others cried when she stood there, because they could not come to her without crossing an apparent chasm. The experiment thus demonstrated that most human infants can discriminate depth as soon as they can crawl. The behavior of the children in this situation gave clear evidence of their dependence on vision. Often they would peer down through the glass on the deep side and then back away. Others would pat the glass with their hands, yet despite this tactual assurance of solidity would refuse to cross. It was equally clear that their perception of depth had matured more rapidly than had their locomotor abilities. Many supported themselves on the glass over the deep side as they maneuvered awkwardly on the board; some even backed out onto the glass as they started toward the mother on the shallow side. Were it not for the glass some of the children would have fallen off the board. Evidently infants should not be left close to a brink, no matter how well they may discriminate depth.

This experiment does not prove that the human infant's perception and avoidance of the cliff are innate. Such an interpretation is supported, however, by the experiments with nonhuman infants. On the visual cliff we have observed the behavior of chicks, turtles, rats, lambs, kids, pigs, kittens and dogs. These animals showed various reactions, each of which proved to be characteristic of their species. In each case the reaction is plainly related to the role of vision in the survival of the species, and the varied patterns of behavior suggest something about the role of vision in evolution.

In the chick, for example, depth perception manifests itself with special rapidity. At an age of less than 24 hours the chick can be tested on the visual cliff. It never makes a "mistake" and always hops off the board on the shallow side. Without doubt this finding is related to the fact that the chick, unlike many other young birds, must scratch for itself a few hours after it is hatched.

Kids and lambs, like chicks, can be tested on the visual cliff as soon as they can stand. The response of these animals is equally predictable. No goat or lamb ever stepped onto the glass of the deep side, even at one day of age. When one of these animals was placed upon the glass on the deep side, it displayed characteristic stereotyped behavior. It would refuse to put its feet down and would back up into a posture of defense, its front legs rigid and its hind legs limp. In this state of immobility it could be pushed forward across the glass until its head and field of vision crossed the edge of the surrounding solid surface, whereupon it would relax and spring forward upon the surface.

At the Cornell Behavior Farm a group of experimenters has carried these experiments with kids and goats a step further. They fixed the patterned material to a sheet of plywood and were thus able to adjust the "depth" of the deep side. With the pattern held immediately beneath the glass, the animal would move about the glass freely. With the optical floor dropped more than a foot below the glass, the animal would immediately freeze into its defensive posture. Despite repeated experience of the tactual solidity of the glass, the animals never learned to function without optical support. Their sense of security or danger continued to depend upon the visual cues that give them their perception of depth. The rat, in contrast, does not depend predominantly upon visual cues. Its nocturnal habits lead it to seek food largely by smell, when moving about in the dark, it responds to tactual cues from the stiff whiskers (vibrissae) on its snout. Hooded rats tested on the visual cliff show little preference for the shallow side so long as they can feel the glass with their vibrissae. Placed upon the glass over the deep side, they move about normally. But when we raise the center board several inches, so that the glass is out of reach of their whiskers, they evince good visual depth-discrimination: 95 to 100 per cent of them descend on the shallow side.

Cats, like rats, are nocturnal animals, sensitive to tactual cues from their vibrissae. But the cat, as a predator, must rely more strongly on its sight. Kittens proved to have excellent depth-discrimination. At four weeks—about the earliest age that a kitten can move about with any facility—they invariably choose the shallow side of the cliff. On the glass over the deep side, they either freeze or circle aimlessly backward until they reach the center board. The animals that showed the poorest performance in our series were the turtles. The late Robert M. Yerkes of Harvard University found in 1904 that aquatic turtles have somewhat poorer depth-discrimination than land turtles. On the visual cliff one might expect an aquatic turtle to respond to the reflections from the glass as it might to water and so prefer the deep side. They showed no such preference: 76 per cent of the aquatic turtles crawled off the board on the shallow side. The relatively large minority that choose the deep side suggests either that this turtle has poorer depth-discrimination than other animals, or that its natural habitat gives it less occasion to "fear" a fall.

All of these observations square with what is known about the life history and ecological niche of each of the animals tested. The survival of a species requires that its members develop discrimination of depth by the time they take up independent locomotion, whether at one day (the chick and the goat), three to four weeks (the rat and the cat) or six to 10 months (the human infant). That such a vital capacity does not depend on possibly fatal accidents of learning in the lives of individuals is consistent with evolutionary theory.

To make sure that no hidden bias was concealed in the design of the visual cliff we conducted a number of control experiments. In one of them we eliminated reflections from the glass by lighting the patterned surfaces from below the glass (to accomplish this we dropped the pattern below the glass on both sides, but more on one side than on the other). The animals—hooded rats—still consistently chose the shallow side. As a

test of the role of the patterned surface we replaced it on either side of the centerboard with a homogeneous gray surface. Confronted with this choice, the rats showed no preference for either the shallow or the deep side. We also eliminated the optical difference between the two sides of the board by placing the patterned surface directly against the undersurface of the glass on each side. The rats then descended without preference to either side. When we lowered the pattern 10 inches below the glass on each side, they stayed on the board.

We set out next to determine which of two visual cues plays the decisive role in depth perception. To an eye above the center board the optical pattern on the two sides differs in at least two important respects. On the deep side distance decreases the size and spacing of the pattern elements projected on the retina. "Motion parallax," on the other hand, causes the pattern elements on the shallow side to move more rapidly across the field of vision when the animal moves its position on the board or moves its head, just as nearby objects seen from a moving car appear to pass by more quickly than distant ones (Fig. 2). To eliminate the potential distance cue provided by pattern density we increased the size and spacing of the pattern elements on the deep side in proportion to its distance from the eye (Fig. 3, top). With only the cue of motion parallax to guide them, adult rats still preferred the shallow side, though not so strongly as in the standard experiment. Infant rats chose the shallow side nearly 100 per cent of the time under both conditions, as did day-old chicks. Evidently both species can discriminate depth by differential motion alone, with no aid from texture density and probably little help from other cues. The perception of distance by binocular parallax, which doubtless plays an important part in human behavior, would not seem to have a significant role, for example, in the depth perception of chicks and rats.

Two types of visual depth-cue are diagrammed schematically on this page. Ellipses approximate the visual field of an animal standing near the edge of the cliff and looking toward it; diagrams at right give the geometrical explanation of differences in the fields. The spacing of the pattern elements (solid color) decreases sharply beyond the edge of the cliff (top). The optical motion (shaded color) of the elements as the animal moves forward (center) or sideways (bottom) shows a similar drop-off. To eliminate the cue of motion parallax we placed the patterned material directly against the glass on either side of the board but used smaller and more densely spaced pattern-elements on the cliff side. Both young and adult hooded rats preferred the side with the larger pattern, which evidently "signified" a nearer surface. Day-old chicks, however, showed no preference for the larger pattern. It may be that learning plays some part in the preference exhibited by the rats, since the young rats were tested at a somewhat older age than the chicks. This supposition is supported by the results of our experiments with animals reared in the dark.

The effects of early experience and of such deprivations as dark-rearing represent important clues to the relative roles of maturation and learning in animal behavior. The first experiments along this line were performed by K. S. Lashley and James T. Russell at the University of Chicago in 1934. They tested light-reared and dark-reared rats on a "jumping stand" from which they induced animals to leap toward a platform placed at varying distances. Upon finding that both groups of animals jumped with a force closely correlated with distance, they concluded that depth perception in rats is innate. Other investigators have pointed out, however, that the dark-reared rats required a certain amount of "pretraining" in the light before they could be made to jump. Since the visual-cliff technique requires no pretraining, we employed it to test groups of light-reared and dark-reared hooded rats. At the age of 90 days both groups showed the same preference for the shallow side of the apparatus, confirming Lashley's and Russell's conclusion.

Recalling our findings in the young rat, we then took up the question of whether the dark-reared rats relied upon motion parallax or upon contrast in texture density to discriminate depth. When the animals were confronted with the visual cliff, cued only by motion parallax, they preferred the shallow side, as had the light-reared animals. When the choice was cued by pattern density, however, they departed from the pattern of the normal animals and showed no significant preference (Fig. 5). The behavior of dark-reared rats thus resembles that of the day-old chicks, which also lack visual experience. It seems likely, therefore, that of the two cues only motion parallax is an innate cue for depth discrimination. Responses to differential pattern-density may be learned later.

One cannot automatically extrapolate these results to other species. But experiments with dark-reared kittens indicate that in these animals, too, depth perception matures independently of trial and error learning. In the kitten, however, light is necessary for normal visual maturation. Kittens reared in the dark to

the age of 27 days at first crawled or fell off the center board equally often on the deep and shallow sides. Placed upon the glass over the deep side, they did not back in a circle like normal kittens but showed the same behavior that they had exhibited on the shallow side. Other investigators have observed equivalent behavior in dark-reared kittens; they bump into obstacles, lack normal eye movement and appear to "stare" straight ahead. These difficulties pass after a few days in the light. We accordingly tested the kittens every day. By the end of a week they were performing in every respect like normal kittens. They showed the same unanimous preference for the shallow side. Placed upon the glass over the deep side, they balked and circled backward to a visually secure surface. Repeated descents to the deep side, and placement upon the glass during their "blind" period, had not taught them that the deep side was "safe." Instead they avoided it more and more consistently. The initial blindness of dark-reared kittens makes them ideal subjects for studying the maturation of depth perception. With further study it should be possible to determine which cues they respond to first and what kinds of visual experience accelerate or retard the process of maturation. From our first few years of work with the visual cliff we are ready to venture the rather broad conclusion that a seeing animal will be able to discriminate depth when its locomotion is adequate, even when locomotion begins at birth. But many experiments remain to be done, especially on the role of different cues and on the effects of different kinds of early visual experience.

References

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