CLOSE ENCOUNTERS OF A FOURTH KIND: WHAT RICHARD DREYFUS MIGHT HAVE LEARNED ABOUT PERCEPTUAL ADAPTATION

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I. THE PROBLEM

At the end of Steven Spielberg's cinematic masterpiece, *Close Encounters of the Third Kind*, we see Richard Dreyfus climbing aboard the alien aircraft, destined for a new and unusual planet in a distant universe. In my musings about the untold future scenes of the film, I like to think of this alien world to which Dreyfus travels as being totally new and beyond our experience; as having different forms of energy, physical laws, and energy relationships. As a psychologist, the most interesting speculation about Dreyfus' new life on this planet has to do with whether he will ever be able to perceive things in the way the natives do; indeed, whether he will be able to perceive things veridically at all. As we shall see, I suspect that Dreyfus himself would never be able to adapt to an extremely novel environment, although if he had had the foresight to invite his youngest child along for the vacation, the child might have ultimately made the perceptual adjustment. my reasoning is that Dreyfus' adult nervous system has already matured and developed in accord with the kinds of informational constraints present in the earthly environment. Since it has adapted to one environment, it will be relatively inadequate for perception in a new environment. On the other hand, Dreyfus' child, while endowed with the neural circuits required for interaction with the earth environment, has a nervous system that is still "plastic" or modifiable, so that adaptation to the new environment will be possible.

We don't actually have to be planet hoppers to study how the brain comes to know about its environment--even our apparently mundane earth provides enough questions about the sources of perceptual knowledge. Philosophers have long debated whether the child enters our world equipped with the perceptual (and intellectual) machinery required for interaction with the environment (the nativist position) or whether that child can only slowly build up an understanding of the world through the integration of relevant experiences (the empiricist position). While this paper is not intended to be a philosophical tract, it is worthwhile to consider some of the positions that have been forwarded. In order to keep the topic of this paper within certain constraints, I will offer the following restricted definition of knowledge, towards which the later discussions will be directed: "Knowledge is the capacity to discriminate things." For the psychologist, the "things" being discriminated are usually various stimuli that can be measured and analyzed in terms of physical parameters. For the philosopher, the "things" might be somewhat more complicated. My assumption, based upon a review of the physiological literature, is that discrimination occurs to the extent that a) a given neural network responds differentially in the presence of a physically different stimuli, or b) different physical stimuli elicit similar responses in functionally different neural networks.

Although John Locke (a British Empiricist) never met Steven Spielberg (an American Capitalist), I suspect that they might have had some interesting conversations. Without needing to consider space travel to brave new worlds, Locke saw the infant as being born into a somewhat alien environment without the slightest innate knowledge of its properties. His notion of the child as a tabula rasa upon which the external objects of reality more or less imprinted themselves found a somewhat more recent proponent in the psychologist William James, who described the infant's world as a blooming, buzzing confusion. George Bishop Berkeley went a developmental step further to suggest that the visual recognition of objects and of depth relationships must be educated by the sense of touch. On the other side of the philosophical coin were arguments from Kant, who claimed that space perception is a necessary pre-condition for interpreting experience, and from Descartes, who claimed that our most compelling ideas must derive from knowledge born to the soul. Who is right? Are we born into the world genetically prepared by evolution to perceptually interact with our environment, or must experience essentially create within us the machinery needed to perceive the objects we most frequently encounter? As is often the case in long-standing debates (e.g., whether light is a particle or wave phenomenon), it now appears that neither group is entirely correct, although neither group is entirely wrong either. Apparently, the newborn individual is born with circuits prepared to respond to features of the environment. However, nature has also provided us with the means of rearranging these circuits in case we find ourselves on alien terrain (metaphorically speaking, of course).

II. RESTRICTED ENVIRONMENTS AND BRAIN DEVELOPMENT

Upon first encountering the nature-nurture issue in General Psychology students propose hypothetical experiments in which people or animals are raised in worlds devoid of stimulation, or in unusual environments. Unfortunately, controlled experiments of this type can't really be carried out with humans at this time; however, in some cases nature has provided us with the requisite preparations. And as for animals, thus far many have been raised in the most unusual earthly environments imaginable, all with the object of learning more about brain plasticity. before discussing the results of these "restricted experience' experiments, however, it is imperative to discuss what is known about the perceptual abilities of the newborn brain.

A. INNATE FEATURES OF THE NEWBORN CORTEX Physiological studies of the functional properties of cells in the visual cortices of newborn cats and monkeys have shown us, among other things that a) most cells respond best to bars or edges of a particular orientation and are relatively unresponsive to stimuli of other orientations (called orientation detectors--interestingly, the majority of orientation detectors seem to prefer vertical or horizontal contours; there is a relative paucity of "oblique detectors"); b) many cells respond est to motion of a stimulus, and in particular, respond vigorously to motion is a preferred direction and little or not at all to motion in the orthogonal direction (called directionally selective motion detectors); c) cells in certain regions of the cortex receive input from each of the two eyes and respond to stimulation of either eye. It has further been shown that the latter class of cells is necessary for stereopsis and depth perception--the ability to fuse the disparate views of the world received by each eye and use the disparity to determine depth sensations. The important thing to note is that, according to extensive studies by David Hubel and Torsten Wiesel, who shared last year's Nobel prize in physiology with Roger Sperry, these cells are functional at birth. They may not respond with the precision of adult cells, but they appear to share the same properties of function. thus, to some extent, the Nativists were correct: There is the innate ability to respond to features of the environment in the absence of relevant experience. Furthermore, evoked potential and behavioral studies of newborn human infants suggest that they possess these same types of neural circuits.

B. MODIFICATION OF ORIENTATION DEFECTORS In order to determine how experience affects the development of these inborn circuits, Blakemore & Cooper and Hirsch & Spinelli independently reared kittens in environments that contained contours of a single orientation. For example, Blakemore & Cooper raised their kittens in large cylinders, the sides of which were painted with either horizontal or vertical bars. At maturity, the cats that had undergone this "environmental surgery" behaved as though they were blind to orthogonal contours. For example, cats reared in a vertical environment ran into horizontal barriers placed in their cases, although they were adept at avoiding vertical barriers. When Blakemore & Cooper subsequently penetrated the occipital lobes of these animals and recorded the activity of individual cells in response to stimuli imaged on the cats' eyes, it was found that, unlike normal animals, nearly all cells responded to contours of the rearing condition only. An interesting additional finding of these studies was that adult cats were not at all affected by similar treatment. The rearrangement of cortical specificity occurred only during a "sensitive period" from two weeks of age to about 4 months of age, with the most sensitive time coming at about the fifth week of life. In these animals, the nature of the stimulation apparently modified the innate circuits of the brain to meet an environmental pressure.

The results of Hirsch & Spinelli's research was in some ways even more impressive. Those experimenters fitted newborn kittens with specially designed goggles, one lens of which transmitted only vertical contours and the other only horizontal contours. Thus, for example, he right eye might have only seen vertical contours; the left eye, only horizontals. After the animals were allowed to mature, Hirsch & Spinelli examined the response properties of neurons in the visual cortices of these cats. They found that, unlike the cells in the brains of normal animals, any individual cell in the visual areas of these brains was responsive to stimuli presented to one eye only. As you might expect, the cell responded only to contours oriented in the same direction as those seen by the given eye during rearing. Although such an animal may not have suffered from a split personality, it is true that half of the brain knew only vertical as reality; half, only horizontal. Imagine what might happen if these two halves of the brain ever had an argument regarding the true nature of the universe.

Lest we think that the above experiments are trivial and irrelevant, it should be noted that nature sometimes conducts a similar experiment with humans. In the optical condition known as astigmatism, the abnormal shape of the cornea alters the focus of visual images upon the retina so that some orientation, usually either vertical or horizontal, is not well focused. Unfortunately, if an infant suffers from astigmatism, the difficulty is frequently not discovered until the child begins reading lessons, sometimes even later. Ralph Freeman and others have shown that if the condition is not corrected during some "critical period" in humans, the patient will never attain the same acuity or sensitivity to contours of the deprived orientation that normal observers have. Evoked potential studies show that the lasting deficit is cortical, not ocular.

C. MODIFICATION OF CORTICAL BINOCULARITY In a series of experiments, our Nobel Prize-winners, Hubel & Wiesel, raised kittens either with a patch over one eye, or with one eye sutured shut during the critical period of development. As adults, these cats had cortical cells with inputs only from the experienced eye. Although the deprived eye was normal physiologically, it lacked the power to drive cortical cells, as if the brain had decided that no reliable information could be obtained from the deprived eye and therefore "shut it off." Further studies have shown that the absence of pattern on the retina, not the absence of light, is responsible for this effect. Another crucial deficit in these cats was that, having what one would call a "monocular brain," they lacked the ability to correlate the images provided by the two eyes in order to perceive depth. However, the plasticity of the brain is apparently so robust during the sensitive period that the effects of such, monocular deprivation can be completely reversed if the patches themselves are simply reversed in the second half of the critical period. Accidentally, some humans have been subjected to the same types of deprivation. In some unfortunate cases, children with eye infections have worn patches over an eye during just the peak of the critical period for the development of binocular cells in the brain. Of course, the consequence is that they now have amblyopia, of "weak eye," in the deprived eye, especially during night driving. The effect must be localized in the brain, since electrophysiological recordings show the neural activity of the retina to be normal.

D. ARTIFICIAL STRABISMUS AND THE BRAIN In order for the brain to make the proper association between inputs from the two eyes, the information from those eyes must be correlated in some way. in strabismus, or "wandering eye," a muscle imbalance of at least one eye points the two eyes in noncorresponding directions. The consequence is that the visual images are not correlated. Hubel and Wiesel raised kittens with surgically induced muscle imbalances. They found that the adult brain of these cats had essentially "turned off" the input from the aberrant eye. Again, most cells responded only to information received from the eye pointing in the normal direction. Once again, depth perception was severely impaired in these animals. The same results can be obtained if an animal simply wears a displacing prism over one of its eyes during development.

Inasmuch as strabismus frequently affects young humans, we find very much the same problem in them as adults. They frequently suffer from amblyopia and faulty depth perception. If the condition is surgically corrected in adulthood, the effect is cosmetic only; if corrected early enough in childhood, normal development proceeds.

The changes in cortical binocularity that occur in the last two sets of experiments we have been studying appear to be mediated by an inhibitory competition between the genetically determined inputs of the two eyes. that is, there is a sort of competition between developing axons for conical receptor sites. An axon arising from the deprived or surgically altered eye may lose some of its competitive edge and subsequently be inhibited by the axons of the more exercised eye. These effects, in turn appear to be mediated by catecholaminergic pathways, possibly in dopamine containing neurons.

E. OTHER WEIRD WORLDS Before the point of these experiments becomes tedium, it is worth noting that our brave, if coerced, infant kittens and monkeys have been raised in even stranger environments: under strobe-light illumination to prevent the development of motion detectors; with continually moving contours--in one direction only--to bias the development of directionally selective mechanisms; with circular contours only, to inhibit the development of orientationally selective bar detectors, etc. The results are almost always the same: In the adulthood of these early-deprived animals, cells of the brain respond maximally to stimuli similar to those experienced in critical sensitive period; subjecting an adult to such worlds produces virtually no effect.

The results of the above studies suggest that the developing brain enters the world "prepared" to respond to what the evolution of genetic mechanisms prescribed to be a normal environment. Nonetheless, the brain is perfectible and can rearrange its circuits to accommodate new demands arising in the environment. However, once the circuits mature, certain basic organizations cannot be further modified, and perceptual deficits may result if the environment changes itself again. This is why I believe the Richard Dreyfus would not have adjusted to his new habitat in a faraway galaxy, while his child might have. However, this conclusion is predicted on the notion that the new environment would contain features that are alien to Dreyfus' experience. On the other hand, Dreyfus might have been able to make some compensatory changes in his perceptual system to accommodate some not-too-extreme changes in his new environment. In the next section we see that even the adult nervous system retains some plasticity.

III. ADAPTATION TO REARRANGED INPUT

Returning to our galaxian traveler, Richard Dreyfus, imagine what would happen if he stepped off of the alien starship onto a world in which light is refracted in a way exactly opposite of how it is refracted here on earth, meaning that the images focused on Dreyfus' retina would be upside down relative to their earthly orientations. In fact, whenever Dreyfus would reach for an object that appeared to be above him, he would miss, because the object would really be below. Similarly, whenever he would look up he would see his feet; when looking down he would see the beautiful six moons of this planet. His confusion no doubt would be great, but after a few days of nausea, he might just begin to undergo a perceptual adjustment to the situation. Studies conducted by Ivo Kohler back here on earth indicate that after volunteers wore inverting prisms for a few days, they generally persisted in perceiving the world upside down. However, objects did appear objectively upright when they were being handled. Ultimately, the entire perceptual world of the subjects righted itself (most of the time) so that subjects were able to maneuver in the world normally, even participating in activities like skiing and bicycle riding in busy streets. Interestingly, when the subjects ultimately removed their inverting prisms, so that the world was imaged on their retinas in a manner the same as you and I, the world once again appeared upside down and they needed a new period of readjustment.

The fact that the subjects wearing the inverting prisms first saw those objects that they handled as being rightside up suggested to Richard Held that in these situations of perceptual rearrangement, the visual system might make compensatory changes in organization to match the input of the kinesthetic and touch senses of the body. He subsequently found that individuals could only adapt to the effects of wearing prisms if they were allowed to perceive the consequences of their own movements. For example, subjects who were prevented from seeing their own hands and feet never adjusted to altered visual input. Similarly, individuals who first put on displacing prisms (those that simply shift the world over a few degrees) and who subsequently were taken for a ride on a wheelchair through the environment never adapted to the rearranged input; those who walked through the same route did.

This area of research has culminated in some rather definitive experiments by Charles Harris that demonstrate that when an individual perceptually adapts to the effects of wearing prisms, the adaptation isn't in the visual system at all, but rather in the individual's felt positions of his body parts. For example, when wearing lenses that reverse left-right relations, the subject literally comes to feel the left side of his body as being the right, and the right side as being to the left. Thus, despite Berkeley's suggestion that touch must educate vision, it appears that the opposite is actually the case. This point was demonstrated dramatically when Harris had his subjects wear prisms that perceptually rounded the edges of square objects so that they appeared to be circular. When subjects were allowed to handle these objects under a cloth, so that the outline of the object was visible and subjects could not see their own hands, the subjects uniformly reported feeling a circular object

IV. CONCLUSION

The overall conclusion of such studies is that a person can adapt perceptually to global shifts in the environment, shifts that come into conflict with the position sense. However, the adaptation appears to be in the person's own self-image, not in the way he actually codes the world visually. thus, the things that we want to call a percept really arises in an interactive system that requires a code for external information and a "self" that fits the code into its current cognitive structures, or schemata. Fortunately, the schemata appear to be updated and modified as the environment demands. the experiments on "environmental surgery" that we discussed earlier suggest that an organism enters the world genetically prepared to respond to certain environmental information. The code for responding to features in the environment can be modified during early experience, should the environment prove to be other than what cons of evolution predicted it would be. As the animal develops its perceptual-motor systems, it comes to correlate the things that it sees with what it is feeling and with the feeling of the positions of its own body parts. Should it subsequently encounter a global shift in the environment (as opposed to a change in the nature of the features of the environment themselves), the organism possess the plasticity to alter its perceptual self-image of its body parts, environmental relationships like "up-down" and "rightleft", etc. -- in order to accommodate the new input of the world. What was the evolutionary pressure that selected for such plasticity of the self-image? No doubt, the changes in the ability of the human lens to change its focus with age was one factor. Additionally, the subtle changes environmental refraction and gravitational pull that occur as the species spread to different altitudes may have been another. Not to mention the fact that members of the human species come in a wide variety of physical statures and muscle structures, each unique combination of which would require a different correlation between a perceptual code and a self-image. One might even speculate that the slow change in going from a medium of water to a medium of air, with their different refractive indexes, created a pressure for the species to develop a modifiable perceptual system.

At any rate, real space travelers can be grateful for the fail-safe perceptual-adaptation system that nature has provided them. Otherwise, we might never be able to adapt to a zerogravity environment, one in which there is no objective up or down, possibly not even a right or left Perhaps Mother Nature intuitively knew that her earthbound creatures might someday try to conquer new and distant worlds.

V. TAKE-HOME QUIZ

To reward you for your patience I shall now challenge you to answer a take-home quiz. Imagine that you and one other human being (preferably of the opposite sex) grew up alone on a tropical island. There are, of course, no mirrors on the island, and the winds make the water too choppy to see reflections in. So. . . you have seen no other human face than that of your friend for 21 years (to make this an adult fairy tale). One day while you are out gathering bananas, a passing tour boat with 1000 passengers sees your friend on the, beach, sends a party of sailors ashore, who carry her (him) off to the boat in what they think is a rescue. When you return, you notice your partner is missing, see the boat, and swim to it to find your friend. Your task, of course, is to distinguish your friend, with whom you have been in constant and exclusive contact for your 21 years of life, from among the other 1000 passengers with their various faces, body-builds, etc. And your friend, of course, might be waiting for you. The question is, could you ever find one another again? Did all those years of experience with the friend imprint her (his) image on your brain so firmly that you would immediately recognize her in a crowd? Believe it or not, psychologists have conducted analogous studies in the laboratory.