since his surgery, had not possessed these abilities prior to this study. Among the many implications of this discovery is the possibility that this patient's brain was able to learn skills out of necessity, that otherwise would probably never have developed. This study lends further support for the notion that our brains may have abilities far beyond those we actually use.

Finally, some researchers are exploring the possibility that independent functioning of the two hemispheres of the human brain may help explain various psychological conditions known as dissociative disorders in which a person undergoes a major shift in identity and consciousness (e.g., Schiffer, 1996). Dissociative conditions include Multiple Personality Disorder (MPD), fugue states, and psychogenic (meaning not due to any physical illness or injury) amnesia. The idea behind this notion is that in some people with intact, nonsplit brains, the right hemisphere may be able to function at a greater-than-normal level of independence from the left, and may even take control of a person's consciousness for periods of time. This may offer a plausible explanation for dissociative psychological disorders, especially if the left hemisphere has little or no memory of these episodes, and, therefore, the person cannot talk about them and would very likely deny their existence. So, is it possible that multiple personality disorder might be the *expression* of hidden personalities contained in our right hemispheres? It's something to think about . . . with *both* hemispheres.

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MORE EXPERIENCE = BIGGER BRAIN?

Rosenzweig, M. R., Bennett, E. L., & Diamond, M. C. (1972). Brain changes in response to experience. *Scientific American, 226,* 22–29.

If you were to enter the baby's room in a typical American middle-class home today, you would probably see a crib full of stuffed animals and various colorful toys dangling directly over and within reach of the infant. Some of these toys may light up, move, play music, or do all three. What do

you suppose is the reasoning behind supplying infants with so much to see and do? Well, aside from the fact that babies seem to enjoy and respond positively to these things, it is most parents' belief, acknowledged or not, that children need a stimulating environment for optimal intellectual development and proper development of the brain.

The question of whether certain experiences produce physical changes in the brain has been a topic of conjecture and research among philosophers and scientists for centuries. In 1785, Malacarne, an Italian anatomist, studied pairs of dogs from the same litter and pairs of birds from the same batches of eggs. For each pair, he would train one subject extensively over a long period of time while the other would be equally well cared for, but not trained. He discovered later, in autopsies of the animals, that the brains of the trained animals appeared more complex, with a greater number of folds and fissures. However, this line of research was, for unknown reasons, discontinued. In the late 19th century, there were attempts to relate the circumference of the human head with the amount of learning a person had experienced. While some early findings claimed such a relationship, later research determined that this was not a valid measure of brain development.

By the 1960s, new technologies had been developed that gave scientists the ability to measure brain changes with great precision using high magnification techniques and assessment of levels of various brain enzymes and neurotransmitter chemicals. Mark Rosenzweig and his colleagues Edward Bennett and Marian Diamond, at the University of California at Berkeley, incorporated those technologies in an ambitious series of 16 experiments over a period of ten years to try to address the issue of the effect of experience on the brain. Their findings were reported in the article discussed in this chapter. For reasons that will become obvious, they did not use humans in their studies, but rather, as in many classic psychological experiments, their subjects were rats.

THEORETICAL PROPOSITIONS

Since psychologists are ultimately interested in humans, not rats, the use of nonhuman subjects must be justified. In these studies, part of the theoretical foundation concerned why rats had been chosen as subjects. The authors explained that for several reasons, it is more convenient to use rodents than to use higher mammals such as carnivores or primates. The part of the brain that is the main focus of this research is smooth in the rat, not folded and complex as it is in higher animals. Therefore, it can be examined and measured more easily. In addition, rats are small and inexpensive, which is an important consideration in the world of research laboratories (usually underfunded and lacking in space). Rats bear large litters, and this allows for members from the same litters to be assigned to different experimental conditions. Finally, the authors point out, various strains of inbred rats have been produced, and this allows researchers to include the effects of genetics in their studies if desired.

Implicit in Rosenzweig's research was the belief that animals raised in highly stimulating environments will demonstrate differences in brain growth and chemistry when compared with animals reared in plain or dull circumstances. In each of the experiments reported in this article, 12 sets of three male rats, each set from the same litter, were studied.

METHOD

Three male rats were chosen from each litter. They were then randomly assigned to one of three conditions. One rat remained in the laboratory cage with the rest of the colony; another was assigned to what Rosenzweig termed the "enriched" environment cage; and the third was assigned to the "impoverished" cage. Remember that there were 12 rats in each of these conditions for each of the 16 experiments.

The three different environments (Figure 1) were described as follows:

1. The standard laboratory colony cage contained several rats in an adequate space with food and water always available.
2. The impoverished environment was a slightly smaller cage isolated in a separate room in which the rat was placed alone with adequate food and water.
3. The enriched environment was virtually a rat's Disneyland (no offense intended to Mickey!). Six to eight rats lived in a "large cage furnished with a variety of objects with which they could play. A new set of playthings, drawn out of a pool of 25 objects, was placed in the cage every day" (p. 22).

The rats were allowed to live in these different environments for various periods of time, ranging from 4 to 10 weeks. Following this differential treatment period, the experimental rodents were humanely sacrificed so that autopsies could be carried out on their brains to determine if any differences had developed. In order to be sure that no experimenter bias would occur, the examinations were done in random order by code number so that the person doing the autopsy would not know in which condition the rat was raised. The researchers' primary focus was on the differences in the brains of the enriched rats vs. the impoverished rats.

The rats' brains were dissected and the various sections were measured, weighed, and analyzed to determine amount of cell growth and levels of neurotransmitter activity. In this latter measurement, there was one brain enzyme of particular interest called *acetylcholinesterase*. This chemical is important because it allows for faster and more efficient transmission of impulses among brain cells.

Did Rosenzweig and his associates find differences in the brains of rats raised in enriched vs. impoverished environments? Here are their results.

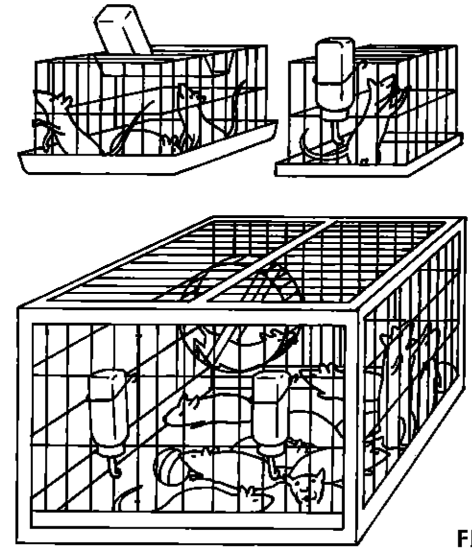

FIGURE 1 The three cage environments.

RESULTS

Results indicated that the brains of the enriched rats were different from the impoverished rats in many ways. The cerebral cortex of the enriched rats was significantly heavier and thicker. The cortex is the part of the brain that responds to experience and is responsible for movement, memory, learning, and all sensory input (vision, hearing, touch, taste, smell). Also, greater activity of the nervous system enzyme acetylcholinesterase, mentioned previously, was found in the brain tissue of the rats with the enriched experience.

While there were no significant differences found between the two groups of rats in the number of brain cells (called neurons), the enriched environment produced larger neurons. Related to this was the finding that the ratio of RNA to DNA, the two most important brain chemicals for cell growth, was greater for the enriched rats. This implied that there had been a higher level of chemical activity in the enriched rats' brains.

Rosenzweig and his colleagues stated that "although the brain differences induced by environment are not large, we are confident that they are genuine. When the experiments are replicated, the same pattern of differences is found repeatedly. . . . The most consistent effect of experience on the brain that we found was the ratio of the weight of the cortex to the weight of the rest of the brain: the sub-cortex. It appears that the cortex increases in weight quite readily in response to experience whereas the rest of the brain changes little" (p. 25). This measurement of the ratio of the cortex to the rest of the brain was the most accurate measurement of brain

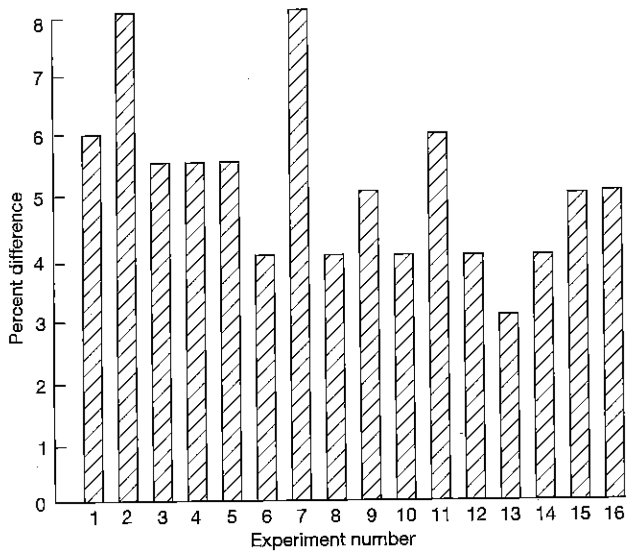

FIGURE 2 Ratio of cortex to rest of brain: Enriched compared with impoverished environment. (Results in experiments 2 through 16 were statistically significant.) (adapted from p. 26)

changes. This was because the overall weight of the brain varies with the overall weight of each individual animal. By considering this ratio, such individual differences are canceled out. Figure 2 illustrates this finding for all of the 16 studies. As you can see, in only one experiment was the difference not statistically significant.

Finally, there was a finding reported relating to the synapses of the brains of the two groups of rats. The synapse is the point at which two neurons meet. Most brain activity occurs at the synapse, where a nerve impulse is either passed from one neuron to the next so that it continues on, or it is inhibited and stopped. Under great magnification using the electron microscope, it was found that the synapses themselves of the enriched rats' brains were 50 percent larger than those of the impoverished rats.

DISCUSSION AND CRITICISMS

After nearly ten years of research, Rosenzweig, Bennett, and Diamond were willing to state with confidence, "There can now be no doubt that many aspects of brain anatomy and brain chemistry are changed by experience" (p. 27). However, they were also quick to acknowledge that when they first reported their findings many other scientists were skeptical, since such effects had not been so clearly demonstrated in past research. There were criticisms contending that perhaps it was not the enriched environment that produced the brain changes, but other differences in the treatment of the rats such as mere handling or stress.

The criticism of differential handling was a valid one in that the enriched rats were handled twice each day when they were removed from the cage as the toys were being changed, while the impoverished rats were not handled. It was possible, therefore, that the handling might have caused the results and not the enriched environment. To respond to this potential confounding factor, the researchers handled one group of rats every day and did not handle another group of their litter mates (all were raised in the same environment). No differences in the brains of these two groups were found. Additionally, in their later studies, both the enriched and impoverished rats were handled equally and, still, the same pattern of results was found.

As for the criticisms relating to stress, the argument was that the isolation experienced by the impoverished rats was stressful and this was the reason for their less developed brains. Rosenzweig et al. cited other research that had exposed rats to a daily routine of stress (cage rotation or mild electric shock) and had found no evidence of changes in brain development due to stress alone.

One of the problems of any research carried out in a laboratory is that it is necessarily artificial. Rosenzweig and his colleagues were curious about how various levels of stimulation might affect the brain development of animals in their natural environments. They pointed out that laboratory rats and mice often have been raised in artificial environments for as many as 100 generations and bear little resemblance genetically to rats in the wild. To explore this intriguing possibility, they began studying wild deer mice. After the mice were trapped, they were randomly placed in either natural outdoor conditions or the enriched laboratory cages. After four weeks, the outdoor mice showed greater brain development than did those in the enriched laboratory environment. "This indicates that even the enriched laboratory environment is indeed impoverished in comparison with a natural environment" (p. 27).

Finally, the most important criticism of any research involving animal subjects is the question of its relationship, if any, to humans. There is no doubt that this line of research could never be performed on humans, but it is nevertheless the responsibility of the researchers to address this issue, and these scientists did so.

The authors explained that it is difficult to generalize from the findings of one set of rats to another set of rats, and consequently much more difficult to try to apply rat findings to monkeys or humans. And, although they report similar findings with several species of rodents, they admit that more research would be necessary before any assumptions could be made responsibly about the effects of experience on the human brain. They proposed, however, that the value of this kind of research on animals is that "it allows us to test concepts and techniques, some of which may later prove useful in research with human subjects."

Several potential benefits of this research were suggested by the authors in their article. One possible application was in the study of memory. Changes in the brain due to experience might lead to a better understanding of how memories are stored in the brain. This could, in turn, lead to new techniques for improving memory and preventing memory loss due to aging. Another area in which this research might prove helpful was in explaining the relationship between malnutrition and intelligence. The concept proposed by the authors in this regard was that malnutrition may make a person unresponsive to the stimulation available in the environment and consequently may limit brain development. And, the authors noted, some concurrent research suggested that the effects of malnutrition on brain growth may be either reduced by environmental enrichment or enhanced by deprivation.

RELATED RESEARCH AND RECENT APPLICATIONS

This work by Rosenzweig, Bennett, and Diamond served as a catalyst for continued research in this area. Over the more than 25 years since the publication of their article, these scientists and many others have continued to confirm, refine, and expand their findings.

For example, it has been found that learning itself is enhanced by enriched environmental experiences and that even the brains of adult animals raised in impoverished conditions can improve when placed in an enriched environment (see Bennett, 1976, for a complete review). Moreover, it has been found that enriched experiences may increase the secretion of certain neurotransmitter chemicals that enhance learning (Woody, 1986).

There has been some evidence to indicate that experience does indeed alter brain development in humans. Through careful autopsies of humans who have died naturally, it appears that when a person develops a greater number of skills and abilities, the brain actually becomes more complex and heavier. Other findings come from examinations during autopsies of the brains of people who were unable to have certain experiences. For example, in a blind person's brain, the portion of the cortex used for vision is significantly less developed, less convoluted, and thinner than in the brain of a person with normal sight.

Marian Diamond, one of the authors of the original article, has applied the results of work in this area to the process of human intellectual development throughout life. She says, "For people's lives, I think we can take a more optimistic view of the aging brain. . . . The main factor is stimulation. The nerve cells are designed for stimulation. And I think curiosity is a key factor. If one maintains curiosity for a lifetime, that will surely stimulate neural tissue and the cortex may in turn respond. . . . I looked for people who were extremely active after 88 years of age. I found that the people who use their brains don't lose them. It was that simple" (Hopson, 1984, p. 70).

Rosenzweig's study has been included in a discussion by Ellen Langer on mental flexibility versus rigidity (see a discussion of Langer's work on personal control and aging in the Human Development section of this book). She contends that a lack of environmental enrichment may result in "mindless" inflexible behavior patterns and a reduced ability to cope with novel situations (Langer, 1992). Finally, a study by Schore (1996) applied Rosenzweig's notions of environmental influences on brain development to mental illness in humans. Shore contends that an infant's early emotional experiences in relation to the primary caregiver actually influence the production of certain brain chemicals that play a role in the physical development of the cortex, the part of our brain that is responsible for our most sophisticated and complex functions such as thinking, perception, and emotion. When the emotional attachment of the infant to the caregiver is stressful and unsatisfying, the hormones created in the infant's nervous system cause the abnormal development of specific structures and circuits in the cortex of the brain that are responsible for regulating emotional reactions. According to Shore, this abnormal brain development triggered by negative environmental factors during the critical growth period of birth to two years of age, creates an enduring increased susceptibility to various psychological disorders later in life (p. 59).

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WHAT YOU SEE IS WHAT YOU'VE LEARNED

Turnbull, C. M. (1961). Some observations regarding the experiences and behavior of the BaMbuti Pygmies. *American Journal of Psychology, 74,* 304–308.

This study is a somewhat unusual one to appear in this book. Turnbull did not have any specific theoretical propositions, there was no clear scientific method used, and the author is not a psychologist. Nevertheless, this short article has been frequently and widely cited to demonstrate some important psychological concepts relating to your ability to perceive the world around you. Before reaching the point where Turnbull's observations can be placed in the proper context, a considerable amount of conceptual explanation is necessary. Keep in mind that we will get to the study itself, even though we may seem to be taking the long way around. Let's begin by filling in the theory behind Turnbull's discoveries, which the brevity of his article did not allow him to do.