56% were left-brain oriented. However, when the same methods were applied to 180 students in various, *specialized* upper-level courses, the range of left brain students ranged from 38% to 65%. This difference indicated that something about a person's brain hemispheres was associated with spreading students out over a variety of college degrees and interests. Second, and more revealing, Morton employed the same method in determining the hemispheric orientation of members of various professions in university settings. The findings indicated that hemispheric specialization appears to be predictive of professional choices. For example, among biochemists Morton found that 83% were left-brain oriented, while among astronomers only 29% showed a left-brain preference (p. 319). You can see how this would make sense in relation to Sperry and Gazzaniga's work. Biology and chemistry rely more heavily on linguistic abilities, whereas astronomers must have greater abilities in spatial relationships (no pun intended).

CONCLUSION

Some have carried this, seperate-brain idea a step further and applied it to some psychological disorders, such as dissociative, multiple personality disorder (e.g., Schiffer, 1996). 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 it may even take control of a person's consciousness for periods of time. 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* of your hemispheres.

Gazzaniga, M. S. (1985). *The sodal brain.* New York: Basic Books.

Gazzaniga, M. S., & Ledoux.J. E. (1978). *The integrated mind.* New York: Plenum Press.

Hommet, C, & Biliard, C. (1998). Corpus callosum syndrome in children. *Neurochirurgie, 44(1),* 110-112.

Levy,J. (1985, May). Right brain, left brain: Fact and fiction. *Psychology Today,* 42-44.

Morton, B. E. (2003). Line bisection-based hernisphericity estimates of university students and professionals: Evidence of sorting during higher education and career selection. *Brain and Cognition, 52(3),* 319-325.

Parsons, L., Gabrieli.J., Phelps, E., & Gazzaniga, M. (1998). Cerebrally lateralized mental representations of hand shape and movement. *Neuroscience, 18(16),* 6539—6548.

Puente, A. E. (1995). Roger Wolcott Sperry (1913-1994). *American Psychologist,* 50(11), 940-941.

Schiffer, F. (1996). Cognitive ability of the right-hemisphere: Possible contributions to psychological function. *Harvard Review of Psychiatry,* 4(3), 126-138.

Sperry, R. W. (1968). Hemisphere disconnection and unity in conscious awareness. *American Psychologist, 23,* 723-733.

Reading 2: MORE EXPERIENCE = BIGGER BRAIN

Rosenzweig, M. R., Bennett, E. L, & Diamond, M. C. (1972). Brain changes in response to experience. *Scientific American, 226(2),* 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 or 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 parents' reasoning behind providing infants with so much to see and do? Aside from the fact that babies seem to enjoy and respond positively to these toys, most parents' believe, whether they verbalize it or not, that children need a stimulating environment for optimal intellectual development and brain growth.

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, Vincenzo 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 participant extensively over a long period of time while the other would be equally well cared for but untrained. 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, attempts were made to relate the circumference of the human head with the amount of learning a person had experienced. Although 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 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 10 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

Because psychologists are ultimately interested in humans, not rats, the validity of using nonhuman subjects must be demonstrated. In these studies, the authors explained that, for several reasons, using rodents rather than higher mammals such as primates was scientifically sound as well as more convenient. 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. The authors point out that 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 3 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, 12 rats were placed in each of these conditions for each of the 16 experiments.

The three different environments (Figure 2-1) 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 slighdy smaller cage isolated in a separate room in which the rat was placed alone with adequate food and water.

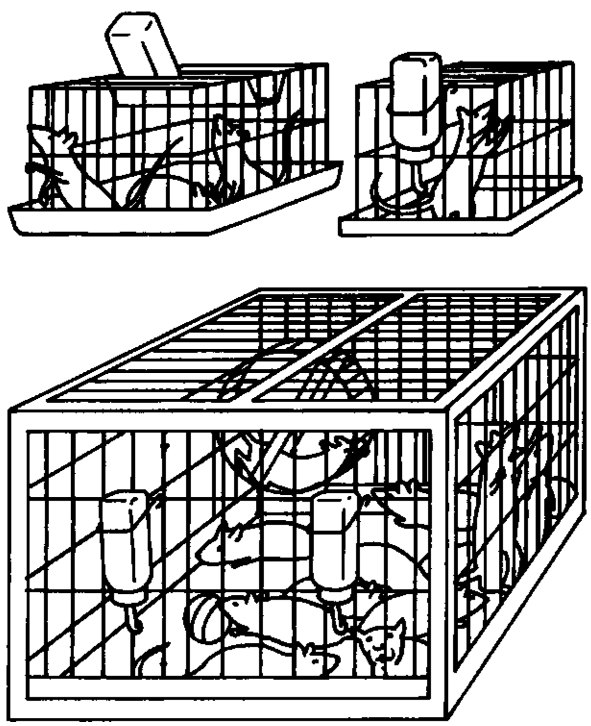

FIGURE 2-1 Rosenzweig's three cage environments.

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 examined to determine if any differences had developed in brain development. 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 rats' brains were then measured, weighed, and analyzed to determine the amount of cell growth and levels of neurotransmitter activity. In this latter measurement, one brain enzyme was of particular interest: *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 versus impoverished environments? The following are their results.

RESULTS

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

Although no significant differences were found between the two groups of rats in the number of brain cells *(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 a higher level of chemical activity had taken place 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 changes because the

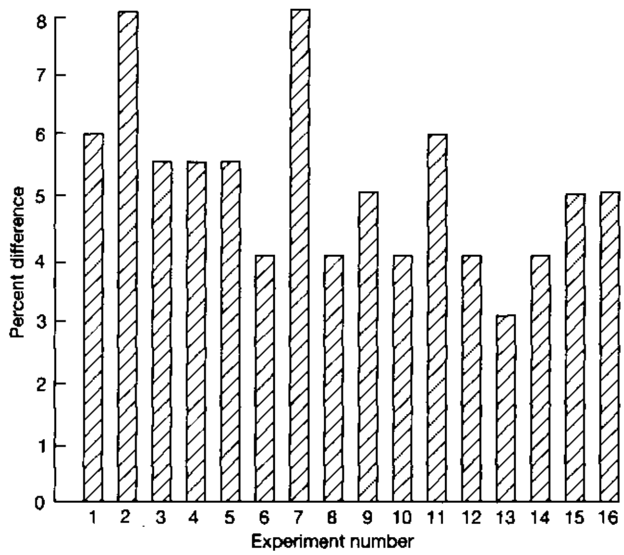

FIGURE 2-2 Ratio of cortex to the rest of the brain: enriched compared with impoverished environment. (Results in experiments 2 through 16 were statistically significant.) (Adapted from Rosenzweig, Bennett, & Diamond, p. 26.)

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

The researchers reported a finding relating to the two rat groups' brain *synapses* (the points 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, the researchers found that the synapses of the enriched rats' brains were 50% larger than those of the impoverished rats, potentially allowing for increased brain activity.

DISCUSSION AND CRITICISMS

After nearly 10 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 because such effects had not been so clearly demonstrated in past research. Some criticism contended that perhaps it was not the enriched environment that produced the brain changes but rather 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, but the impoverished rats were not handled. It was possible, therefore, that the handling alone might have caused the results and not the enriched environment. To respond to this potentially 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). Rosenzweig and his associates found no differences in the brains of these two groups. In addition, 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 nearly always an artificial environment. 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 a hundred generations and bear little genetic resemblance 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 4 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).

The most important criticism of any research involving animal subjects is the question of its application, if any, to humans. Without a doubt, 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 it is 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" (p. 27).

Several potential benefits of this research were suggested by the authors. One possible application pertained to 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 be a person's responsiveness to the stimulation available in the environment and consequently may limit brain development. The authors also noted that other studies suggested that the effects of malnutrition on brain growth may be either reduced by environmental enrichment or increased by deprivation.

RELATED RESEARCH AND RECENT APPLICATIONS

This work by Rosenzweig, Bennett, and Diamond has served as a catalyst for continued research in this developmental area that continues today. Over the decades since the publication of their article, these scientists and many others have continued to confirm, refine, and expand their findings. For example, research has demonstrated that learning itself is enhanced by enriched environmental experiences and that even the brains of adult animals raised in impoverished conditions can be improved when placed in an enriched environment (see Bennett, 1976, for a complete review).

Some evidence exists to indicate that experience does indeed alter brain development in humans. Through careful autopsies of humans who have died naturally, it appears that as a person develops a greater number of skills and abilities, the brain actually becomes more complex and heavier. Other findings have 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 this 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" (in Hopson, 1984, p. 70).

Two recent studies have elaborated on Rosenzweig, Diamond, and Bennett's notions of environmental influences on brain development in very diverse applications. Weiss and Bellinger (2006) expanded on the research by suggesting that studies of the effects of environmental toxins on early brain development in humans must encompass not only the toxicity of the chemical but also should consider all the factors present within the individual's overall life context, including genetic tendencies and enriched or impoverished environments. The authors proposed that, in humans, the effects of exposure to toxic substances tends to be direcdy related to growing up in an enriched versus an impoverished environment. In other words, when children are raised in poverty, not only is their developmental environment likely to be impoverished, but they may also be at a greater risk of exposure to neurotoxic chemicals. Moreover, the environmental factors that are present can affect the outcome of the toxic exposure on brain development. Weiss and Bellinger asserted that when researchers have studied environmental toxins, the tendency has been to focus on the toxic substance itself and to minimize the accompanying situational variables. As the authors stated:

> We argue that the outcomes of exposure to neurotoxic chemicals early in life are shaped by the nature of a child's social environment, including that prevailing before birth . . . . We contend that a true evaluation of toxic potential and its neurobehavioral consequences is inseparable from the ecologic setting [such as environmental richness] in which they act and which creates unique, enduring individual vulnerabilities." (p. 1497)

Another article cites Rosenzweig's 1972 study in critiquing some recent attempts to oversimplify enrichment strategies in attempts to enhance children's brain development (Jones & Zigler, 2002). As you can imagine, when the public learns about research such as Rosenzweig's, a popular movement may be born that sounds attractive but has little basis in scientific fact. One of these from the 1990s, which you may have heard about, has become known as the "Mozart Effect" This fad began with some preliminary research showing that when children listen to Mozart (but not other classical composers) they become better learners. This idea has grown to the point that entire Web sites are devoted to the benefits of the "Mozart Effect" for children and adults alike, involving claims that certain music can enhance overall health, improve memory, treat attention deficit disorder, reduce depression, and speed healing from physical injuries.

CONCLUSION

Jones and Zigler (2002) maintain that such popular applications of the research are ineffective and even dangerous. They contend, "Brain research is being misappropriated to the service of misguided 'quick fix' solutions to more complicated, systemic issues" (p. 355). They further suggest that when scientific brain and learning research is applied carefully and correctly, it can make a "substantive contribution of high quality, intensive, multidomain interventions to early cognitive and social development" (p. 355).

Bennett, E. L. (1976). Cerebral effects of differential experience and training. In M. R. Rosenzweig & E. L. Bennett (Eds.), *Neural mechanisms of learning and memory.* Cambridge, MA: MIT Press.

Hopson, J. (1984). A love affair with the brain: A PT conversation with Marian Diamond. *Psychology Today, 11,* 62-75.

Jones, S., & Zigler, E. (2002). The Mozart Effect: Not learning from history. *Journal of Applied Developmental Psychology, 23,* 355-372.

Weiss, B., & Bellinger, D. C. (2006). Social ecology of children's vulnerability to environmental pollutants. (Commentary). *Environmental Health Perspectives, 114,* 1479-1485.