

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 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 nineteenth 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 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

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).

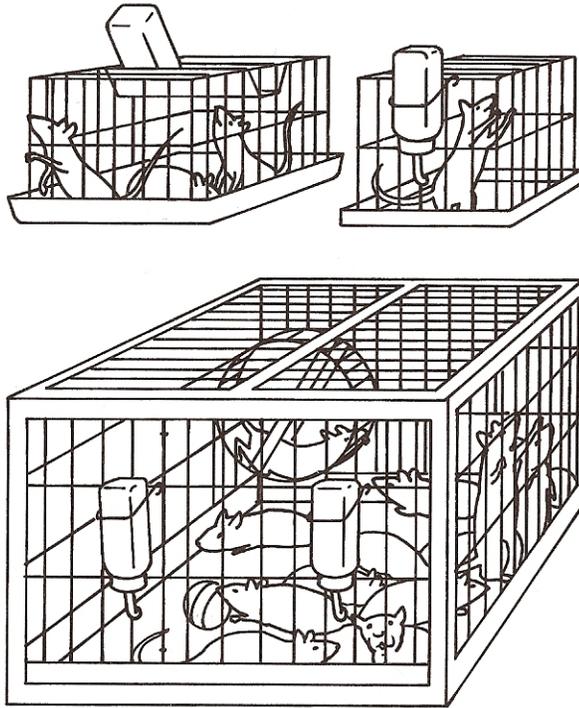


FIGURE 1 The three cage environments.

The rats were allowed to live in these different environments for various periods of time, ranging from four 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 versus 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 versus impoverished environments? Here are their results.

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 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% larger than those of the impoverished rats.

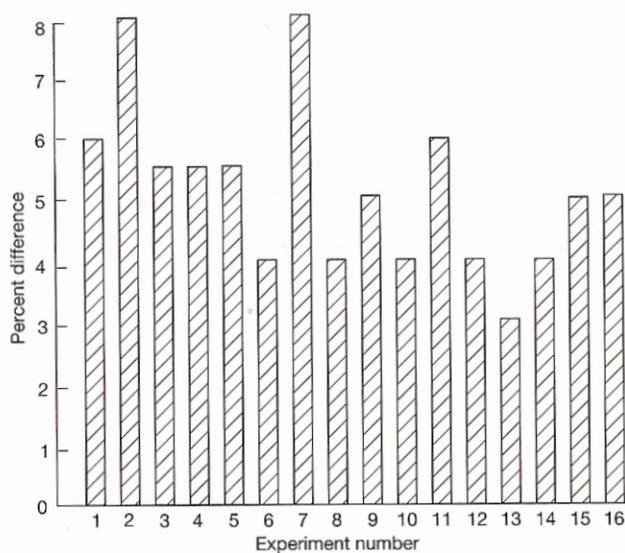


FIGURE 2 Ratio of cortex to rest of brain: Enriched compared with impoverished environment. (Results in experiments 2 through 16 were statistically significant.) (Adapted from p. 26.)

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, 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).

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 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).

Finally, two recent studies have elaborated on Rosenzweig, Diamond, and Bennett's notions of environmental influences on brain development in very diverse applications, and on two very diverse species. Addressing the issue discussed earlier relating to the problem of applying research on rats to other animals, one

study examined the effects of early enrichment on an animal clearly more complex and more intelligent than rats: pigs (Sneddon et al., 2002). In this study, 84 piglets were raised in either impoverished or enriched environments from birth to 14 weeks old. In this case, rather than toys, the enriched pig environment contained extra space with peat and straw for play and comfort. At 15 to 17 weeks of age, the pigs from both groups were tested on an operant learning task in which they learned to push on a panel to receive a food reward, and a maze-learning test (see the reading on B. F. Skinner in the learning and conditioning chapter in this book for more about operant conditioning). As you might predict from Rosenzweig's research, the "pigs from enriched environments learned both the operant task and the maze task more rapidly than their counterparts from barren environments" (Sneddon et al, p. 373). Although the cognitive development of pigs may not be terribly important to humans, this study allows us to apply Rosenzweig's rat study to other animals, including humans, with greater confidence that such a generalization may, indeed, be valid.

Another recent study cites Rosenzweig's 1972 study in critiquing some recent attempts to oversimplify enrichment strategies for enhancing 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. 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).

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