

Early Experience, Relative Plasticity, and Cognitive Development*

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This paper examines the roles of early experience and relative plasticity in the cognitive development of animals and humans. It is concluded that: (a) long-term effects of early experience variables can be found in the animal and human literature; (b) there are age differences in the relative susceptibility to environmental influences during development; (c) despite qualitative differences in the mechanisms underlying the dependent variables studied in the early experience literature, there are generally applicable principles involving the intensity of environmental stimulation and the buffering ability of the organism which are crucial in affecting the outcome of organism-environment interactions; (d) a variety of models is required to adequately describe the mediation of environmental effects in the early experience literature.

Issues surrounding the relative plasticity of behavior have given rise to considerable controversy. Central to the discussion is the usefulness of viewing behavioral development as involving age-based periods that are optimal or most vulnerable to environmental stimulation. Although some version of a sensitive period theory has a demonstrated usefulness in the study of animal behavior (see, for example, Immelmann & Suomi, 1982), the application of this body of theory to human behavior has been contested (Clarke & Clarke, 1976; Kagan, Kearsley, & Zelazo, 1978; Sameroff, 1975). This paper is a review of data and theory relevant to the proper status of this concept in our views of human and animal cognitive development.

While no term has achieved general usage, the idea of a sensitive period involves "the conviction that experience can exert a greater influence at some times of life than others" (Bateson, 1979, p. 470). I will use the term *sensitive period*, or speak of relative plasticity; that is, relative susceptibility to environmental influences. Although the theory of sensitive periods is multifaceted (Bateson, 1976, 1979; Gollin, 1981), this review will be especially concerned with the manner in which aspects of the stimulus, particularly the intensity of the environmental stimulus, interact with sensitive period phenomena. (See also Bronfenbrenner [1968] and MacDonald [1985] for reviews of early experience and social development which emphasize the importance of the intensity of environmental stimulation.) Several animal studies using a variety of paradigms have shown that increasing the

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intensity or duration of ecologically appropriate stimulation results in prolonged sensitivity to environmental stimulation. For example, Bronson and Desjardins (1970) found that injection of female mice at birth with testosterone propionate (TP) had a more masculinizing effect than injection on Day 12. Moreover, if injection was delayed until Day 30, a much longer period of injection was required to achieve the same effect (Edwards, 1970). Similarly, Barraclough (1966) found that a progressively larger dose of TP was needed to induce acyclicity in females at later ages. At 5 days of age, 5 mg of TP were sufficient to lower the percentage of cycling females to 56%. At 10 days of age, 1250 mg gave a similar percentage. Thus, a larger dose or more intensive treatment is required at the later age. The organism is increasingly refractory to environmental stimulation.

The definition of the intensity of stimulation presents a number of difficulties. Fowler (1983a) states that the term can apply to "the frequency with which stimulation is conducted over a given period, the length of the training sessions, the pace at which stimulation is conducted within a session, and [most importantly] the ratio of the volume of concepts exposed to the time expended" (p. 311). Such definitions essentially conceive of environmental stimulation as varying from extremely deprived to extremely enriched. Another useful and related aspect of a definition of intensity involves deviation from an average or normal level of environmental stimulation. For example, Bronfenbrenner (1968), in reviewing the effects of early experience on social behavior, argues that the degree of deprivation is an important variable in the effect produced by early environments. In the present case it will be argued that the data show that major deviations from average expected environments tend to have long-range effects on cognitive development and that intensive stimulation, in the sense of Fowler (1983a), is useful in remediating the effects of environments that are below average in stimulation or involve physical insult to the organism.

Implicit in this point of view is the idea that many of the genetic systems underlying behavior in humans and a wide variety of animals, especially the mammals, are environment-expectant in that they structure the response of the organism to expected environmental variation (MacDonald 1984, 1985). For example, in the area of social development, the affective systems appear to provide for graded responses to the types of environmental stimulation that are in fact found in all human environments—the presence or absence of caretakers, the sensitivity of the caretaker to the signals of the infant, as well as the degree to which the caretaker provides social stimulation to the child, such as eye contact or tickling.

Clearly there are important qualitative differences in the types of stimulation to which these genetic systems respond, and Fowler (1983a) lists several such dimensions relevant to cognitive development. In the present context a variety of different dependent and independent variables will be discussed, ranging from linguistic functioning to IQ, and from perinatal insults to increased cognitive stimulation. Clearly different mechanisms are involved in these phenomena, but this fact does not preclude the search for a unified theory. Indeed researchers and theorists in the area of early experience have generally assumed that the theory of

sensitive periods was at least potentially applicable to a wide variety of empirical phenomena, ranging from the learning of appropriate mates for some bird species, to maze learning in rodents, to cognitive and linguistic functioning in children. Here it will be argued that the expected environments can vary not only in a qualitative manner, but also in a quantitative manner from a modal or average level, and this appears to have important effects on behavior. In the case of cognitive development it will be argued that quantitative variation in environments such as those relevant to nutrition and perinatal complications, as well as the ratio of volume of concepts to time expended, are important to understanding the early experience literature.

Such a definition would allow for the inclusion of certain extremely deleterious physical environments, such as malnourishment and perinatal trauma, as well as the standard educational enrichment-deprivation idea into a single theoretical framework. Intensity of stimulation is thus perceived as defined by a family of characteristics involving graded differences in stimulation departing from average or normative levels and including unusually enriched environments as well as those that are extremely deprived or physically insulting. The possibility that such a definition could apply to a broad range of phenomena in both animals and humans is an important possibility that should be investigated. (See Bronfenbrenner [1968] and MacDonald [1985] for a variety of examples showing the importance of such a definition of intensity of stimulation to the social development of animals and humans.) As is the case with scientific concepts generally, the usefulness of a definition depends on there being empirical data to which the definitions apply.

From a broad evolutionary viewpoint, there is much variation in the degree to which different species (as well as different behaviors within species) make use of environmental input in order to produce adaptive phenotypes. For many species the environment has a very minor role to play during development. However, humans and many mammals have evolved a plasticity which allows for the possibility of rapid response to environmental contingencies. But this plasticity is a two-edged sword (MacDonald, 1985) which necessitates adapting to graded levels of environmental stimulation, some of which may be maladaptive. Many of our social problems would disappear if human development were more tightly constrained genetically so that development was immune from socially rejecting or cognitively unstimulating environments. From an evolutionary engineering standpoint, however, it is difficult to design an organism which is at the same time highly sensitive to environmental variation as well as immune from the effects of extreme levels of that variation.

The major thesis argued here, then, is that age-based differences in relative plasticity and the intensity of environmental stimulation are important variables required in order to understand the early experience literature. In addition, I will present evidence for the existence of long-range effects of particular early environmental variables and discuss several models for the mediation of the effects of early experience. I will not discuss here other qualitative aspects of the stimulus that undoubtedly play an important role in the effectiveness of early experience variables (see Fowler, 1983a, 1983b, for an extended treatment of this problem).

ANIMAL STUDIES

Animal research on early environmental influences on learning should not be easily dismissed, since essentially similar results have been found for a variety of species ranging from rodents to primates. Moreover, as will be seen below, the general principles of age-based differential plasticity and the importance of the intensity of environmental stimulation are quite consistent with the human literature. These results help establish a rationale for fitting the available human data in a comparative framework, although the multidimensionality of environmental influences in human cognitive development (Fowler, 1983a, 1983b; Wachs & Gruen, 1982) makes it plausible that at least some relevant dimensions of the human situation will not be adequately covered by animal models. Indeed, the multiplicity and specificity of environmental influences found in the human literature may well lead to animal models geared to assessing the effects of very specific environmental manipulations rather than the predominance of general enrichment-deprivation paradigms.

Data using adult performance on mazes as the endpoint indicate long-lasting effects of early experience in an enriched environment for rats, effects found long after differences between environments were removed (see Greenough, 1976, for a review). Hymovitch (1952) found that the effects of enriched experience lasted 75 days after the difference in environments was removed and testing was discontinued after this time. Hebb (1949) found that rats that lived as pets in his home until 3 months of age had higher maze test scores at 8 months and describes the effect as permanent. In addition, Forgays and Read (1962) found that a group given free-environment experience from Days 0-21 were superior on maze performance at 123 days to a control group. Finally, Denenberg, Woodcock, and Rosenberg (1968) found that animals given early free-environment experience were superior on problem-solving tasks at 1 year of age.

Concerning morphological endpoints, Rosenzweig (1976) states that differences for several endpoints were maintained 47 days after the enriched condition was removed and that tests were not continued after this time, suggesting a long-lasting effect. In addition, work with dogs and rhesus monkeys suggests a similar situation in these species. Dogs isolated until 8 months of age and tested at 2 years of age were poorer at active avoidance tasks, and had impaired pain perception and abnormal EEGs (Melzack & Scott, 1957). Rhesus monkeys subjected to early social restriction were poorer at performing complex oddity problems than monkeys reared in an enriched environment (Gluck, Harlow, & Schlitz, 1973). However, it is important to note that this study found no effects of deprivation on some skills, especially those involving discrimination learning. Thus some skills develop normally even in very deprived environments and are examples of well-buffered behaviors. (See below for a discussion of the concept of well-buffered behaviors.)

Several investigators have found that early experience is more efficient than later experience in producing these effects. Hymovitch (1952) found that rats exposed from Days 30-75 were superior to a group exposed from Days 85-130.

Forgays and Read (1962) found that exposure to an enriched environment from Days 21–42 had more effect than from Days 0–21 or for other 21-day periods starting after Day 42. However, even animals exposed from Days 88–109 were superior to controls. Nyman (1967) and Engold (1956) found that the most effective age was between Days 50–60, with 10-day periods before and after this relatively ineffective. Doty (1972) showed that effects can be gained even at advanced ages. Rats receiving free environment exposure from Days 300–360 were superior to controls on an active avoidance task. Overall, the data support the existence of periods of maximum sensitivity for environmental enrichment near the age of weaning, but suggest that the drop in sensitivity is gradual, and there is no indication that there is any age beyond which environmental stimuli have no effect.

Age has been found to be an important variable for morphological endpoints as well (Uphouse, 1980). Rosenzweig and Bennett (1978) found effects at all ages tested. However, the percent difference decreased as the free-environment experience was started at later ages. For example, 30 of 36 measures of animals starting free-environment experience at Day 26 were significant (24 with $p < .0001$), while for animals starting at Day 282, only 7 of 30 measures were significant (1 with $p < .0001$). Greenough (1976) found no effect of enriched environments on mice started at Day 90, but found an effect if started at Day 30, and evidence is cited that lower order branching in cortical dendrites is not affected by enriched experience after 55 days of age, while higher order branching continues after this age. In addition, Fiala, Joyce, and Greenough (1978) found that an enriched environment affected dendritic branching in young rats but not adult rats. Juraska, Greenough, Elliot, Mack, and Berkowitz (1980) found that the terminal length of cortical dendrites was affected in adults exposed to enriched environments, but this treatment did not affect the number of higher order branches in cortical neurons, as had been found in rats of post-weaning age. Thus the adult cortex may show a different type of plasticity than the developing cortex, and the authors suggest that growth in the adult cortex could be potentially transient "with the permanence of the new connections determined by ongoing neural activity" (p. 165). Greenough (1979) also found qualitatively different morphological effects resulting from enriched-environment treatment of adults as opposed to rearing young animals in an enriched environment.

There is clear evidence in this literature for the role of the intensity and duration of appropriate environmental experience. Forgays and Forgays (1952) found graded effects on maze learning of seven different environmental conditions ranging from social housing in a free environment with playthings to single housing in a laboratory cage. Mean times for completing the maze increased with subtraction of each aspect of enrichment. In addition, the morphological effects of enrichment can be enhanced by giving animals stimulant drugs (Bennett, Rosenzweig, & Wu, 1973) or creating a "super-enriched" environment by either placing the animals in seminatural conditions (Bennett, 1976) or constructing an environment in which survival depended on being able to navigate complex mazes and barriers (Kuenzle & Knusel, 1974). Bennett (1976) comments that these results indicate that

laboratory enriched conditions are good but not optimal, and all of these examples conform to Fowler's (1983a) definition of intensity, since it is reasonable to suppose that all of these manipulations resulted in greater exposure to the relevant environments within a given amount of time. The duration of the enriched condition is also important and interacts with the age of the animal. Rosenweig, Bennett, and Diamond (1972) found that rats exposed to enriched environments at 105 days of age showed similar cortical weight increases to animals started earlier, but longer periods of exposure were required in the former case.

Thus there is considerable evidence for a sensitive period, as we have defined it, for particular morphological effects in these data, but there is no evidence for any age beyond which enrichment is totally ineffective, and there is evidence that intensity and duration of environmental experience can overcome the declining plasticity of the animal. In addition, there may be qualitative differences in the effectiveness of enrichment at different ages as well as quantitative.

HUMAN STUDIES

By far the largest number of theoretically relevant studies on early experience in humans have been done within the framework of general cognitive stimulation rather than specific skill development and the effectiveness of the treatment assessed using IQ tests. Moreover, a few studies have adequately explored the relationships among the variables relevant to the theoretical issues surrounding early experience. In addition, many studies have been performed with very low sample sizes, and/or lack of adequate controls, so that, while they can clearly add to the richness of early experience literature and reinforce the general trends shown by the literature, they cannot stand on their own. (See Fowler [1983a, 1983b] for an excellent summary of this work.) In the following I will examine the best available studies with a view to providing tentative answers to the following questions:

Are there long-term effects of early experience?

Is there age-based differential sensitivity to environmental stimulation?

Is the intensity of stimulation an important variable in early experience research?

Much of the discussion on the effects of early experience on human cognitive development has centered around intervention efforts designed to raise cognitive functioning of children from low-income families, and in particular on the long-term evaluation of 11 independent research projects. (See Lazar and Darlington [1982] for the most recent presentation of these data.) The most important result was that children who had attended preschool were less likely to be assigned to special education classes during school years. The result for the likelihood of assignment to special education classes was particularly robust in several projects. In addition, several projects reported higher achievement results up to the eighth grade, and there was an overall highly significant and robust effect on mathematics achievement. Concerning IQ, treatment children generally performed better than controls for at least the first 3 years after the end of the program. When tested in

1976–1977 at the ages of 9–19, three projects showed significant effects, but these included only children who were under age 13 at follow-up, although small differences in favor of experimental children remained as late as age 16 in some studies. Attendance in preschool also significantly affected parent and child achievement motivation and the child's self-esteem.

It is important to note that the research projects which form the basis of these conclusions varied widely in the intensity of intervention into the lives of the children. Lazar and Darlington (1982) note that the programs

represented relatively small inputs into the children's total lives. Most operated for only a few hours a day over the course of a year or two at most. . . . There were no massive efforts to retrain parents or restructure home environments. (p. 58)

Indeed, the program of Palmer (1978), which was included in these analyses, involved only 2 hours per week of intervention over 8 months. It is important to note that the only program that resulted in mean IQs at the level of general norms was that of Levenstein (1977), which involved a very structured, home-based tutoring program delivered by professionals. Such a program may well have resulted in far more intensive level of intervention in the life of the child than many center-based programs.

The well-known Milwaukee Project (Garber & Heber, 1982) has shown a major effect on IQ as the result of a very intensive "ecological intervention" with children from 3 months to 6 years of age. The intervention consisted of highly structured interaction with adults, a high ratio of adults to children that occurred 8 hours per day, 5 days per week throughout the year. The results showed that the experimental children averaged an IQ of 120 at age 6 compared to an IQ of 94 for controls. Similar results favoring the experimental children were found on language, learning, and problem-solving measures. Although there has been a decline in the experimental children's scores since the termination of the program at age 6, scores remained slightly above population norms at age 10 and 20 points above the levels of controls.

Several studies have been performed in an effort to stimulate the development of specific skills, but few have continued testing for long periods after the intervention. An exception is a study by Carter and Capobianco (1976) who focused on language stimulation with "educationally deprived" first graders and produced an approximately 7-point IQ advantage to the experimental children over 7 years of follow-up testing. These effects were restricted to language learning and verbal IQ and had no effect on non-language IQ or on math and science grades.

The importance of differences in the intensity of the environmental events on cognitive development can be seen in a study that is reminiscent of the study on the stimulation of rats by Forgy and Forgy (1952) discussed above. Hunt, Mohandessi, Ghodssi, and Akiyama (1976) studied five successive waves of Tehran orphanage children whose treatment ranged from minimal institutional care with a 1:10 adult-child ratio to a treatment which included trained caregivers, a 1:3 adult-

child ratio and specialized language-stimulation techniques. In general the results indicated that the degree of competence was proportional to the amount of stimulation the child received. Particularly important was the provision of high adult-child ratios. The study of Garber and Heber (1982) as well as that of Levenstein (1977), discussed above, also suggest the importance of very intensive stimulation such as occurred in the prolonged, daily stimulation characteristic of the Heber study and presumably also occurring in the modified home environment produced by Levenstein's intervention. Adoption into middle-class families is also a very intensive form of stimulation compared to rearing in many lower class environments, and several studies, discussed in greater detail below, have shown dramatic mean gains for the biological offspring of mothers with low IQ if adopted into middle-class homes, particularly if they are adopted early (Scarr-Salapatek & Weinberg, 1976; Skeels, 1966).

The effects of intensity of stimulation in the sense of graded deviations from normal environmental stimulation can be seen in a study by Winick, Meyer, and Harris (1975), who reported that severely malnourished Korean infants adopted prior to age 2 in the U.S. had normal IQs when tested between ages 6 and 17 ($M=102$). However, they still lagged behind a group rated as non-malnourished ($M=112$) and a group of moderately malnourished children ($M=106$). The fact that the effect was found even after random assignment to good backgrounds suggests an important effect of early experience, but considerable, although not complete, resiliency from early deprivation.

Besides the study by Winick et al. (1975), several other studies have shown graded differences in outcome depending on the severity of environmental stressors encountered early in life. Werner and Smith (1982) found a variety of relationships between the severity of pre/perinatal risk factors and long-term outcome in the Kauai longitudinal study. Developmental examinations at 20 months revealed a direct relationship between severity of perinatal stress and the proportion of children rated as below normal on physical, social, or intellectual development, a trend especially pronounced among the moderate and severely stressed children. At age 10 the differences between stressed and unstressed groups were attenuated, but were still quite strong for the group of severely stressed infants. At age 18, four of the five surviving severely stressed infants still had persistent physical, learning, or mental health problems. The group rated as moderately stressed had three times the rate of serious mental problems, twice the rate of mental retardation, and, for girls, over twice the rate of teenage pregnancy. The fact that the differences between stressed and unstressed groups were attenuated over time suggests interaction with later environments in many cases, but the results also indicate important long-term effects of early experience. The relationship between severity of the perinatal stress and the outcome occurred in each socioeconomic class, but subnormal functioning was much higher in the stressed groups in the lower socioeconomic status (SES) group, possibly due to environmental differences related to social class. As an example of the long-term importance of these perinatal events, 60% of children in need of long-term mental health care at age 10 had moderate perinatal stress, low

birthweight, congenital defects, or central nervous system (CNS) dysfunctions. Seventy-five percent of these individuals contacted mental health agencies during adolescence, often for severe and persistent mental health problems. Only one third of them had improved by age 18. Although there is evidence that these children had temperamental characteristics which may have adversely affected parent-child interaction, the results indicate that the relative degree of biological stress is a causal antecedent of the later functioning, and in the present context indicate long-term effects of early experience variables.

As another example, Sigman, Cohen, and Forsythe (1981), working with high-risk infants, found that the severity of the original complication was an important factor in determining the relative influence of parent-child interaction. For some children the physical problem dominated development, and caregiver-infant interactions had a lessened effect. If the number of signs of perinatal anoxia are considered to be an indication of the degree of environmental insult to the newborn, the results of Broman (1979) can also be interpreted as indicating an association between the severity of environmental insult and later impairment. A linear decrease in the frequency of anoxic signs was associated with increasing performance on mental and motor tests for both Black and White subsamples when tested during infancy. At age 7 similar tendencies were apparent for performance on the Wechsler Intelligence Scale for Children (WISC) IQ tests. These results were not confined to lower SES levels. Hunt (1980) also found IQ decrements between 2 and 8 years of age in a middle-class sample of infants born weighing less than 1500 grams. Many of these children showed severe intellectual impairment at 8 years of age. These data again suggest that the degree to which the environment deviates from average levels of stimulation, especially at ages when the organism is poorly buffered, can be a crucial factor in determining if long-term effects occur. Of course, this is not to deny that interactions with later environments can also be important (Sameroff, 1975).

Interestingly, there is evidence that parents of infants at risk stimulate their babies more than parents of normal babies and that this is an adaptive response (Goldberg & DiVitto, 1982; Harmon, 1983; R. D. Parke, personal communication, March 25, 1983; Sigman et al., 1981). In the present context this suggests that parents are attempting to take advantage of the possibility that relatively intense stimulation in a relatively unbuffered organism would be an effective remediation that is, result in interactions with later experience, and this is indeed the interpretation given by Goldberg and DiVitto (1982) to these effects. Another possible example in which the intensity of the environmental input was beneficial comes from the data of Flint (1978), discussed below, in which a very intensive intervention program substantially reversed the deficits of a group that began life in a very inadequate orphanage.

Another example where cognitive development appears to be enhanced by the exposure to very intensive educational environments is the acceleration of gifted children. The acceleration approach to gifted children (see George, Cohn, & Stanley, 1979; and Stanley & Durden, 1983) involves providing intensive academic

instruction in mathematics and sciences to children who have shown evidence of being able to master this material at ages younger than normal. Several studies have shown that students given acceleration outperform students with similar intellectual capacity who are not accelerated. For example, Terman and Oden (1947) found that individuals who were accelerated relative to similarly gifted individuals were more likely to graduate from college and remain for graduate work, showed more occupational success, and more often held professional or upper level business occupations. Similar positive results were reported by the Fund for the Advancement of Education (1953) and Flesher and Pressey (1955) (see Daurio, 1979, for a review). Such studies are consistent with case study data on famous individuals in a variety of fields, showing that these individuals often received intensive early stimulation (see Fowler, 1983a, 1983b, for a review). Other studies of precocious individuals (e.g., Bloom & Sosniak, 1981) also suggest the importance of early intensive stimulation.

Besides long-range effects of preschool intervention, the data on whether some ages are better than others for the effects of educational enrichment must be examined. The program evaluations done by the Consortium for Longitudinal Studies do not support the idea of a sensitive period for early intervention. In the most recent analysis (Lazar & Darlington, 1978), no within or between program effects were found for age of child at entry to the program or for the length of time the program operated. The authors emphasize, however, that the studies were often not really designed with these issues as experimental variables and that the analyses used very conservative statistical techniques and were restricted by the number of observations so that there was very little statistical power. (See Seitz [1981] for a discussion of the problem of statistical power in early intervention research.) Moreover, an independent analysis of Consortium programs (see Lazar & Darlington, 1978) indicated a correlation of $-.64$ between age of child's entry into the program and avoidance of special education classes. In agreement with this, Scarr-Salapatek and Weinberg (1976) found that age of adoption was negatively related to IQ among Black children adopted by White families. Since most of the projects analyzed by Lazar and Darlington (1982) involved children over 3 years old at intervention, the lack of robustness in some results may have been due to their relatively advanced age at intervention. Also, the fact that the interventions were often not very intensive would tend to lessen the chances of finding strong age effects. In any case, these results would not imply a sensitive period because they are consistent with a cumulative effect model, as proposed by Bloom (1964).

Other evidence does indicate that there is differential sensitivity depending on age for the effects of environmental stimulation on cognitive development. Dennis (1973) studied children from an extremely deprived orphanage adopted either before or after age 2. Children adopted prior to age 2 had an IQ of 96 compared to an average IQ of 80 for those adopted later. Children adopted after age 4 had even lower IQs. More importantly, the rate of mental development was significantly higher in the younger children.

The Dennis study has been criticized extensively by Clarke and Clarke

(1976), who suggest that a negative correlation between age at adoption and year of adoption indicates selective factors affected the adoptions. However, this pattern is more likely to be due to a policy change by the orphanage which resulted in the children being allowed to be adopted. At first, many older children were available, but as time went on fewer older children were available, since children were placed for adoption as quickly as possible. Thus the average age of adoption declined over time. Wohlwill (1980) also concludes that the data cannot be explained as being due to selective factors. Secondly, Clarke and Clarke point out that the negative correlation between age adopted and IQ decreases over the 2-year test-retest interval. This would be expected, since older children will tend to gain more IQ points than younger children if their original IQs are lower than the younger children's, and both groups gain at the rate of 1 year of mental age for each year of chronological age, as the data for children adopted after age 2 indicate. For example, a child adopted at age 6 with an IQ of 70 would, on the average, have an IQ of 77 2 years later according to Dennis's data, while a child adopted at age 4 with an IQ of 90 will have an IQ of only 94 2 years later. Because of this, the negative correlation between IQ and age of adoption will be less. Thus the data are better explained as showing a sensitive period beginning around age 2, after which the effects of environmental deprivation are difficult to reverse. The data show, however, that there is considerable individual variation for rate of mental growth, with some older adopted children having IQs greater than 100, and many showing more than 1 year of mental growth for each year of chronological age. Such data can be interpreted as being the result of individual differences in plasticity or as due to greater stimulation encountered by some children after adoption than others.

McKay, Sinisterra, McKay, Gomez, and Floreda (1978) performed a large, well-constructed study of educational intervention in Colombia. The four treatment groups varied the age of beginning treatment and the length of treatment, ranging from four 9-month sessions starting at 42 months of age to one treatment session begun at 75 months of age. The results indicated that it was the treatment gain in the first 9-month session attended by the child that had the strongest effect on the eventual outcome, and that children made more progress in their first 9-month period when starting at younger ages. Thus the greater performance eventually attained by the children who began at the earlier ages is not explainable as being merely due to additive effects contingent on remaining in the program longer than the other groups, but to a greater rate of mental development occurring in the initial stages of intervention when intervention begins at younger ages. When calculated as gains per month during the first 9 months, the group starting at 42 months gained .22 units; those beginning at 52 months, gained .09 units; and those beginning at 63 months, gained .04 units. Further data are given showing that the group starting at 75 months made very slight gains during the first 9 months. In addition, Tizard (1978) found that a small sample of children adopted from a "good" orphanage after age 4½ did not gain in IQ, whereas those adopted between ages 2 and 4 did.

Furthermore, studies by Clarke and Clarke and their associates on the IQ gains of individuals removed from adverse environments are consistent with a

sensitive period theory. Clarke and Clarke (1954) found that adolescents and young adults admitted to an institution for the feeble-minded increased an average of 6.5 IQ points within 27 months to an average of 72.7. It was also found that the largest increases, averaging 9.7 points, were made by those with the most adverse backgrounds, while smaller increases, averaging 4.1 points, were made by individuals with better homes. At follow-up (Clarke, Clarke, & Reiman, 1958) after 6 years, those from adverse homes had increased from an average IQ of 59.6 to 75.8, and this was said to be a minimal estimate because some of those from the worst homes had left the institution because they had been considered fit for discharge. Individuals from more adverse environments tended to improve more rapidly at first, thereafter improving less rapidly. A special intensive rehabilitation program for patients about to be discharged resulted in an insubstantial 2- to 3-point gain in IQ over merely staying in the hospital. The authors concluded that IQ gains resulted mainly from removal from a deleterious environment, not from the positive effects of intensive environmental stimulation. Clearly the results show that IQ is not immutable in later life. Nevertheless, the IQ of those with the most presumed potential (i.e., those from the worst backgrounds) averaged only 78.9 with a range of 64-105 at follow-up. These results indicate that a completely normal distribution was not produced in later life in adolescents and young adults with very adverse early experiences, but rather point to lingering effects of early adversity, with many individuals still in the retarded range. Moreover, even within the original sample of adolescents and young adults studied by Clarke and Clarke (1954) there was a correlation of $-.155$ between age and IQ increment. Taken together with the results reviewed above, the data suggest a gradually increasing refractoriness to environmental stimulation, as predicted by a theory of sensitive periods.

This is not to deny that particularly intensive and ecologically appropriate intervention, as predicted above, cannot reverse cognitive deficits after age 2. The Dennis (1973) study involved no positive environmental intervention other than removal from an unstimulating environment. Evidence that intensive intervention prior to adoption can overcome the declining plasticity is found in a study by Flint (1978). An intensive therapy program for institutionalized children aged 3 months to 3 years involving individual attention, affectively arousing social interactions, and eventual adoption resulted in minimal deficits in IQ at age 15. Besides the early intervention, children and adoptive parents received continued support and consultation with professionals throughout the school years if any problems arose. However, deficits in verbal IQ, thought to be permanent, were found, and there was a significant difference between verbal and performance IQ. A decline rather than improvement in verbal IQ over the course of the study was found. Unlike the Dennis study, there was no significant relationship between eventual IQ and age at which therapy was started, results best interpreted as showing the efficiency of the original intervention rather than lack of differential plasticity depending on the age of the child.

Case studies are notoriously difficult to interpret because of the lack of controls, the use of intensive professional intervention, the lack of knowledge of the

original potential of the individuals, and the extent to which individual differences in susceptibility to environmental stimulation account for the data. Two reports of twins subjected to severe deprivation showed very good outcomes, with post-intervention IQs near normal (Clarke & Clarke, 1976; Koluchova, 1976). Davis (1947) reported on two girls who were severely deprived until age 6½, one of whom made very good progress. The other had a mental age of approximately 2½ when she died at age 10½. Koluchova (1976) also reported on a girl removed at age 4 from an oppressive environment who made considerable progress but continued to have problems with social adjustment as well as a very labile attention span. A recent case described by Curtiss (1978) also showed continuing deficits in cognitive and linguistic functioning. The girl, Genie, severely deprived for 13 years, retained specific language dysfunctions several years after undergoing therapy and remained deficient on several tasks involving left-brain functions, but was normal on right-brain tasks.

The case study data must remain inconclusive, but clearly there are cases that point both ways. The fact that the subjects were twins in four of the five cases with normal or near normal outcome suggests that companionship during isolation may be important for a good outcome. The case of Genie strongly suggests that the organism does not retain its plasticity indefinitely.

The results of Curtiss (1978) are said to support Lenneberg's (1967) critical period hypothesis for the development of language. Other evidence adduced by Lenneberg included the facts that aphasia acquired after puberty tends to be relatively more irreversible with advancing age of onset and that retarded children often advance slowly until puberty when progress stops. In addition, Lenneberg describes evidence showing that deaf children must receive training and prosthesis around age 2 to develop language skills properly. Conversely, children who acquire deafness after short speech exposure are much more likely to make good progress. Recently E. Newport (personal communication, 1982) has found that facility in several aspects of American Sign Language depends on the age of exposure to the language. Native speakers exposed to sign language from birth outperformed individuals exposed at age 4–6, who in turn performed better than individuals first exposed during adolescence when tested up to age 50–60. These differences were most apparent for morphologically complex sequences rather than relatively simple sequences.

INTELLIGENCE AS SPECIES-TYPICAL BEHAVIOR

The previous data indicate that: (a) there are age-based differences in plasticity in humans for the development of intelligence; (b) early experience can have important effects in some cases; (c) whether or not early experience is important depends not only on the age of the individual but also on how extreme the environments he/she encounters are compared to normal environmental stimulation. The data, thus interpreted, do not show that early experience is important for the production of individual differences within the normal range of environmental variation. The best

data for sensitive periods and early experience for humans necessarily come from situations in which individuals have been subjected to extreme environments.

Recently there has been a renewed emphasis on what might be called the view that intelligence is best seen as species-typical behavior (Kagan & Klein, 1973; Scarr, 1976; Scarr & McCartney, 1983). Despite wide variation in human environments, cognitive development is remarkably similar cross-culturally, although the question of whether formal operations or even concrete operations exist in all cultures is controversial, and there is some suggestion that Western-style schooling is necessary for the attainment of formal operations (Dasen, 1981). These data suggest that some aspects of cognitive functioning are well-buffered and fairly independent of variations in normal human environments (see also Kagan & Klein, 1973). Of course, this does not imply that extreme environments will not disrupt these processes; for example, Hunt (1980) has shown that poor institutional environments give rise to delayed acquisition of Piagetian tasks just as they give rise to low IQ scores. The poor prognosis of children from poor institutions for advanced intellectual ability (a high IQ), if unremediated, is well known (Dennis, 1973).

These data convincingly argue that at least some developmental functions are well-buffered from normal environmental variation. However, the question of whether early experience affects individual differences in IQ is quite different from the question of whether it affects the attainment of a particular level of a developmental function (McCall, 1981). Although I know of no data showing that normal variation in early experience is necessary for attaining the various Piagetian stages, there are indications that early experience can have important effects on individual differences in IQ. For example, a study by Schiff et al. (1978) addresses the question of the maximum range of normal environmental effects on intelligence, since it includes only upper middle-class adoptive families (see also Schiff, Duyme, Dumaret, Stewart, & Tomkiewicz, 1982). Children of working class parents whose biological children had an average IQ of approximately 95 had an average WISC IQ of 110.6 when adopted into upper middle-class homes. Assuming an average genetic potential for these children, which is a generous assumption in this case, the results show a 10.6-point increase in IQ due to adoption in upper middle-class homes. This is a minimal estimate of the average effect of environments associated with social class, since the difference between rearing in a below-average, normal environment and rearing in above-average, upper middle-class environments would presumably be much greater, perhaps close to the 15.6-point difference between the biological and adopted children actually observed in this study. The results then indicate that the average effects of rearing in different social classes within the "normal" range of environmental variation is quite large, and presumably therefore a very important contributor to individual differences in a population made up of a variety of social classes.

Moreover, there is evidence that much of the effect of adoption is due to early experience rather than later experience. The transracial adoption study (Scarr-Salapatek & Weinberg, 1976) indicated an important effect of early adoption. Children adopted in the first year of life had an average IQ of 111 compared to an average IQ

of 97.5 for those adopted later. In addition, the difference of 13.5 IQ points associated with early adoption is quite possibly a minimal effect of early adoption, since the criterion of early versus late adoption was 1 year of age. Dennis (1973) found that it was when adoption occurred after age 2 that long-term decrements in IQ were observed due to the fact that on the average the later adopted children could not overcome their original deficit. Thus the differences between early and later adopted groups might well be even more striking if the cutoff point was later. In any case, since the later adopted children had an average IQ of 97.5, while the adopted children had an average IQ of 111, the results suggest that most of the average effect of adoption into middle-class homes is due to early experience rather than later experience. The average effect of middle-class environments, an effect that contributes to individual differences in IQ in a population of different social classes or subcultures, is mostly due to early experience. Again, this represents an underestimate of the effects of early experience since the study does not contrast the results of rearing in below-average, normal environments to the best possible normal environments, but includes instead a population of adoptive families which range from solid working class to upper middle class, approximately two thirds of the IQ range for Whites. Although such a design is well suited to finding correlations between children and their biological and adoptive relatives, it is not suited to answering the theoretically important question of the range of effects of the extremes in normal environmental variation, the question that the studies by Schiff et al. (1978, 1982) do address, or the question of the maximum effect of the normal range of early experience.

The data then show that experience within the normal range affects IQ scores, and early experience is implicated as being important. The data showing that some cognitive abilities, such as the Piagetian stages, are achieved in a very wide range of normal environments are not inconsistent with this, but do suggest that minimal competencies develop even in very deprived environments. For example, Hunt et al. (1976) found that even very deprived orphanage children still went through the same stages of cognitive development as children in more stimulating environments, but at a much slower pace than children in normal environments. Even very deprived children attain some Piagetian stages and increase in mental age. However, the rate at which they attain these stages and increase in mental age is lower, and this has important effects on the eventual level of cognitive functioning attained, as well affecting IQ, since IQ is based on chronological age.

THE MEDIATION OF THE EFFECTS OF EARLY EXPERIENCE

The above data indicate that in many cases behavior is affected by early experiences acting during phases of differential plasticity, but the description thus far has not indicated how these effects are mediated. Discussion of this point is important because if the effects of early experience are mediated by the elicitation of different later environments (i.e., reciprocal organism-environment transactions [Sameroff,

1975]), sensitive periods become of slight importance. Any long-term effect would simply be the result of a deficient organism eliciting or seeking inadequate environments. The contrasting theory regarding the mediation of the effects of early experience is that the environment acts directly on the organism so that the organism is altered, and the eventual outcome is a function of the plasticity of the organism and the power of early and later environments viewed as acting directly on the organism. Later environments may be important, but the role of the organism in eliciting or seeking these environments is minimized.

While the transactional model is of unquestioned importance, and adequately describes much developmental data, it does not by itself adequately take into account either changes in the relative plasticity of the organism or differences in the power of environments in producing effects on the organism. Ignoring differences in the relative plasticity of the organism can result in an overestimation of the reciprocal effects of the environment at some ages, since if the organism is less plastic the environment will be having relatively less effect. Thus even if some individuals elicit their environments, these environments would have a decreasing effect on their behavior if there is declining plasticity. In addition, many environments, especially the intensive environments discussed in the early-experience literature, have their effects relatively independently of the characteristics of the organism. Scarr and McCartney (1983) point out that enriched environments provided by special programs such as Head Start or the adoption of lower SES children into upper SES homes affect the great majority of children in the same way, and the same can be said of deprived environments. These environments have their effects in large part independently of the characteristics of the child, although they may not wipe out individual differences in a group of individuals all of whom receive the same treatment. This makes excellent evolutionary sense. Many genetic systems, such as attachment and cognition, appear to be environment-expectant in that they program for expected environmental stimulation (see MacDonald, 1984, for a discussion of this type of genetic system). If individuals tended as a general rule to have radically different effects on their environments or react to their environments in radically different ways, it would be difficult to develop normative phenotypes or generally effective treatments. Not surprisingly, some of the best documented examples of the transactional model involve highly deviant organisms and their environments, such as those found in child abuse (Parke & Collmer, 1975). On the other hand, behavior genetic studies involving normal populations of twins and adopted children have found little evidence for genotype-environment interactions, suggesting a linear effect of environments on genotypes (Plomin, 1985; Plomin, DeFries, & Loehlin, 1977).

In addition, the transactional model ignores the fact that some individuals may be able to affect their environments much more than others. For example, Scarr and McCartney (1983) propose that active genotype-environment correlations may be much more common as individuals get older and are able to choose their environments rather than passively experience environments provided by parents. As a result, the balance of power in the organism-environment relationship must be seen

as constantly changing throughout the lifespan. In addition, individuals who deviate markedly from the average may be far more effective in eliciting unusual environments than are normal children. Consistent with this, premature babies appear to elicit above-average levels of stimulation from their parents (Crnic, Greenberg, Ragozin, Robinson, & Basham, 1983; Field, 1979; Goldberg & DiVitto, 1982), and difficult babies are more often abused by their parents than normal babies (Parke & Colmer, 1975) and do not benefit from cognitive interventions as well as easy babies (Ramey, MacPhee, & Yeates, 1982).

In order to provide a complete description of the developmental landscape it would appear necessary to provide other models that are useful in describing particular data sets. Thus a particular model is not intended to be a model of cognitive development in general, but to be a model of the relationships revealed by a particular study. As such the models described below are compatible with each other, and there will be no attempt to describe which one is the best model in general. The fact that long-term effects will occur if an organism is exposed to an extremely adverse environment at an early age is not inconsistent with the possibility that extremely stimulating later environments could reverse the effects of the earlier environment. The fact that a behavior is well-buffered from the normal range of environmental variation does not mean that an extreme environmental insult could not have a disastrous effect on the organism. It should also be emphasized that the models are intended to be descriptive, not predictive. The models discussed here are essentially abstracted or generalized descriptions of relationships between events. The models make no predictions, but describing a data set as conforming to a particular model indicates our belief that the variables in the data set have particular relationships, some of which may involve predictability. In the following, several models of early experience will be presented and discussed in light of the data on cognitive development previously described.

The Main Effect Model

The following definition of a main effect will be used: Event E has a main effect on a later behavior B if and only if E is a causally necessary condition for B and subsequent events occurring between E and B do no more than maintain or facilitate the later behavior in the sense of Gottlieb (1976) (see also Aslin, 1981; Gollin, 1981). Thus defined, the main effect model precludes a major role for intervening environments, and in particular rules out the reciprocal role of intervening environments envisioned by the transactional model described below. The best evidence for a main effect model would come from data which showed that there was an association between some early event E which was: (a) unchanged by intervening environments, and (b) occurred independently of the normal range of intervening environments or despite highly enriched later environments.

Thus stated, the main effect model would appear to be of fairly limited applicability. Keeping in mind the fact that enriched environments in the laboratory studies of rodents fall short of the stimulation found in natural environments (Bennett, 1976), the fact that exposure to enriched environments later in life has an

ameliorative effect (Doty, 1972) suggests that the system remains open to significant change later in the life of the animal in environments well within the range of stimulation normal for the species. This may not be the case with some of the areas of the brain (Juraska et al., 1980), and the decrements in learning found by Melzack and Scott (1957) with dogs persisted for long periods of time after isolation and despite later group rearing. Moreover, the fact that some aspects of cognitive and linguistic ability resist significant improvement at later ages despite intense therapy (Curtiss, 1978; Lenneberg, 1967) again suggests a main effect. Nevertheless, apart from these very extreme cases there appears to be sufficient plasticity in humans to make this model a relatively unimportant model for human cognitive development.

The Interactive and Transactional Models

The interactive model assumes that environments occurring later in life have a strong effect on behavior, either attunement or induction (Aslin, 1981; Gollin, 1981; Gottlieb, 1976). Moreover, these later environments have their effects independent of the characteristics of the individuals who experience them. In the transactional model, on the other hand, the characteristics of the person who experiences the environments are also crucial, since these characteristics affect what environments are experienced. Individuals and environments reciprocally affect each other, as in the case of reciprocal interactions between age of menarche and culture described by Lerner (1978). In other cases, the independence of environmental effects from the characteristics of the individual is also an important possibility. Thus the effects of enrichment programs and of parental behaviors associated with a high SES or adoption into good families may be little influenced by variations in child behavior, so that for a broad class of normal and even initially abnormal children, good outcomes are achieved.

From the standpoint of the literature reviewed above, there are no clear cases where the transactional model must be invoked to explain the data. Later environments are often important in producing the behavior, but in general these environments can be seen as generally beneficial or debilitating rather than depending for their effect on reciprocal organism-environment transactions. The rodent data showing the possible importance of later environments (Doty, 1972; Juraska et al., 1980) shows the generally facilitating effects of enriched environments imposed by the experimenter rather than reciprocal effects between organism and environment. The adoption of children into middle-class homes also results in a large effect on cognitive functioning independent of the characteristics of the child (Dennis, 1973; Scarr-Salapatek & Weinberg, 1975; Schiff et al., 1982; Winick et al., 1975). In the latter study (Winick et al., 1975) children differing in degree of early malnutrition all benefited greatly by being placed in adoptive families, with all groups attaining IQ scores above American norms. The differences between the groups that remain after this treatment are thus reasonably thought to be due to differences in the severity of the original problem rather than to important differential reciprocal effects on the environment resulting from these original differences. Although the point made here is that the transactional model has been overemphasized recently, there may indeed be cases where the effects of interventions are strongly influenced

by the characteristics of the person experiencing the intervention. For example, Ramey, MacPhee, and Yeates (1982) found that children described as having a difficult temperament and receiving an intensive intervention program performed worse than controls described as having easy temperaments up to 24 months of age. By 36 months of age, however, both easy and difficult babies subjected to the intervention outperformed the controls, although the easy temperament babies of both groups outperformed the difficult babies within treatment condition. Thus at 36 months of age there was evidence both for an effect of temperament as well as an effect of treatment independent of temperament. Such results suggest the importance of reciprocal, transactional effects for the effects of early experience, but also emphasize the independent role of the environment. Neither should be over-emphasized, since an exclusive emphasis on the transactional model draws attention away from general aspects of the environment that have their effects relatively independently of child characteristics. It is these characteristics that are likely to be of the utmost importance in devising enrichment programs for individuals who are in need.

The Well-Buffered Model

A behavioral system is well-buffered if and only if there are no environmental events within the normal range which attune or induce the behavior in the sense of Gottlieb (1976) and Aslin (1981). Following Scarr (1976), we restrict the application of the well-buffered model to normal environmental variation. Scarr (1976) emphasizes the highly buffered nature of sensorimotor intelligence, and Dasen (1982) emphasizes the similarity of cognitive development at least through the concrete operational stage in a wide range of cultural environments (see above discussion). In addition, if it can be shown that rearing in even highly abnormal environments results in essentially normal behavior, then the well-buffered model also applies. Using this logic, the fact that many cognitive skills remain intact even in isolated rhesus monkeys (Gluck et al., 1973) and in the human case described by Curtiss (1978) indicates considerable buffering of cognitive development. It is important to note that the concept of buffering can apply to either individual differences or developmental functions (McCall, 1981) and that evidence is much better for the latter than the former. Thus Piagetian stages through concrete operations are general features of cognitive functioning which appear to be well-buffered since they develop in a very wide range of normal and even very deprived environments. As emphasized above, well-buffered abilities appear to consist of a set of basic, minimal competencies, and this does not imply that individual differences in cognitive functioning, as measured, for example, by an IQ test or by the rate at which individuals attain the Piagetian stages of development, are not the result of normal environmental variation.

CONCLUSION

Overall, the data on cognitive development do support the existence of long-range effects of early-experience variables in some cases and the existence of age-based

differences in relative plasticity. The data indicate a gradual increase in refractoriness to environmental stimulation rather than a sudden point after which no intervention can have any effect. In addition, the study of Dennis (1973) points to possible individual differences in age-dependent sensitivity to environmental stimulation after severe deprivation. MacDonald (1985) suggests that the appropriate model is one in which the anatomical and physiological structures underlying behavior are present at a very early age in humans, but these structures become increasingly refractory to stimulation so that in some cases reversal is not possible with the present technology. Such a model is consistent with data showing differential plasticity during development as well as data showing that very early stimulation directed at skills such as reading (Fowler, 1983a, 1983b) and intensive stimulation later in development often have beneficial effects. Such a point of view implies important continuity in development. In addition, continuity is implicated by data show that long-term effects of powerful early environments occur, especially in the absence of sufficiently therapeutic later environments. The studies reviewed above showing graded differences in outcome depending on the severity of early stressors and in the presence of normal, later environments indicate continuity with earlier functioning: The environmental event is seen as acting on the organism so that later functioning is affected by the effect of the earlier environment on the organism. In the absence of reasons to suppose that the transactional model applies, and in the presence of normally stimulating later environments, it is strongly suggested that there is continuity of processes internal to the organism.

This review has emphasized the importance of the intensity of ecologically appropriate stimulation in affecting behavior change. Since humans appear to retain significant plasticity throughout development, the intensity of appropriate stimulus becomes of immense practical importance, since it is far easier to manipulate than is the biological basis for declining plasticity. As indicated above, interventions with children at risk for developmental delay as well as with gifted children manipulate the intensity of appropriate stimulation.

Perhaps the most deleterious effect of the recent denigration of the importance of early experience has been the resultant lack of research into the dimensions of early stimulation that are relevant to changing behavior. The emphasis here on the intensity of environmental stimulation should make researchers more conscious of this variable in designing interventions, but research on this dimension has really just begun. Moreover, there has been little systematic research that addresses qualitative dimensions of stimulation which make it ecologically appropriate for the training of specific skills. To find these dimensions may well be equivalent to solving most of the basic problems of cognitive development, since different dimensions of stimulation would quite possibly affect the development of different skills.

In conclusion, the data indicate important constraints on plasticity for human and animal behavior. Of course, this fact does not prevent us from finding ways to intervene with individuals who have suffered early environmental insults. Indeed, the theory of sensitive periods suggests that the intensity of an ecologically appropriate stimulus can, at least up to a point, overcome the organism's declining

plasticity. The data show only that successful intervention is not likely to be easily achieved by behavioral means in some cases. This is not really an earthshaking conclusion, given the existence of a massive industry engaged in oftentimes unsuccessful attempts to change human behavior, but one worth noting in any case.

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