Brainstages

THE ROLES OF BRAIN IN HUMAN COGNITIVE DEVELOPMENT

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ABSTRACT

Brain development in humans occurs stagewise in correlation with the onsets of the main Piagetian stages of reasoning development. This allows a description of cognitive development as resulting partially from and dependent upon biological events occurring in the brain. Evidence shows that some eventual brain structures depend on a combination of biological events and instructional or experiential inputs. Such a description thereby permits some novel working hypotheses about normal cognitive development and how to foster it, as well as suggesting alternative ways of creating intervention programs for children from deprived environments.

Piagetian and Neo-Piagetian theories of human cognitive abilities attempt to describe what happens developmentally leading up to the mature state. They describe this almost entirely in terms of the psycho-social factors involved. But, cognitive functions and changes are more readily and more accurately understood and described if attention is also, if not first, paid to the facts of brain growth. That understanding also permits parents and teachers to see ways to enhance children's cognitive development.

Most of the needed biological information depends on the finding that age-wise correlated growth stages have been shown in human brain weight (Epstein, 1974a, 1986), head circumference (Epstein, 1974a), EEG (Epstein, 1980, Hudspeth and Pribram, 1990), and cerebral blood flow (Epstein, 1999). In addition, the few relevant cytological studies (Conel, 1939-1963; Rabinowicz, 1979) show similar correlations with arborization. Moreover, Rockel et al, (1980) found that, in main cortical areas, the thicknesses of layers III and V are the ones showing by far the greatest increases going up the ladder from mice to humans. It is known that many (most?) neurons in those layers send their axons and dendrites primarily along the cortex to other areas. Thus, evolution has proceeded by increasing the number of contacts among areas (and their characteristic functions); this bespeaks significant additional arborization.

So the stages (3-10 months and 2-4, 6-8, 10-12, and 14-16 years) are now experimental facts and not just theory. These brain growth spurts have been found to occur at the earliest onset ages of the Piaget stages of reasoning development (Epstein, 1980, 1986; Hudspeth and Pribram, 1990); therefore, they are probably the biological bases of the Piaget stages. There is no need to go beyond Piaget to, for example, Gardner's Seven Intelligences because, according to Jensen (1999), Gardner's theory of seven independent intelligences is contradicted by well established correlations between at least four of them: verbal, logical-mathematical, spatial, and musical, and one ability, kinesthetic, probably does not fall into the mental abilities domain.

During rapid brain growth periods the brain weight increases average 5% to 10%, while during the interim periods of slow brain growth, the increase is perhaps 1%.The brain increases include significant expansion of neural network arborization: the elongation and branching of axons and dendrites. The resultant additional and more complex neural networks make possible enhancements in brain functioning, depending for their quality on both the quality of the existing networks that are connected by the added arborization and, also, the quality and quantity of the external inputs that generate the consequent network changes. Because these factors combine individual growth and experiences, age-wise and domain-wise developmental differences will be the norm. From this point of view, the Piaget stages will not necessarily be expected to be acquired in a fixed sequence nor even precisely at the canonical ages given by the Piagetians' studies, although general similarity of early experiences will preserve much of the sequence. Only the biological events occur on an apparently fixed schedule as long as there are no prenatal or postnatal noxious inputs to the children.

Children are born with some genetically prescribed neural networks that subserve the kinds of activities that occur automatically. Breathing, sucking, sensory detection, metabolizing, and similar activities are already programmed into the brain and connections made to appropriate motor controls.

From the day of birth, inputs to the child act on existing networks to strengthen, weaken, modify, and add to their activities. For example, when the child is held and hugged, brain networks are activated and strengthened and firing spreads to associated networks; when the child is sung to, still other networks are strengthened to receive sounds and interpret them as song. The repeated appearance of the mother provides a fixation object much as in imprinting in some animal species. The significant cortical spreading of the effects of apparently simple inputs are just being realized as a result of MRI and PET studies of the effects of such inputs.

Two relevant animal studies illustrating these points will be sketched. Prescott (1998)has reviewed work with macaque monkeys which showed differences between newborns raised by an always present mother and those raised by mothers who were arranged to be present only randomly. By age 2 years, the latter monkeys were fearful in most situations, distressed if separated from the mothers, and socially inept. The work of Ribble (1965) describes the similar events in humans in detail.

Lemonick’s (1997) description of a recent study of young orphan male elephants is also illustrative of this point. These young elephants were raised without being in traditional herds: that is, without the usual matriarchal cow and in the absence of the usual disciplinary elders. When they reached puberty, they went on rampages that are described in the study. Some tried to attach themselves to neighboring herds of rhinoceroses, even trying to mate with their females. Such findings stress that these undisciplined young elephants don't know how to behave, and the problem began much earlier than puberty years for them.
There are small brain growth stages within the first year as shown by Lampl et al (1983), but the first big postnatal brain growth spurt covers the ages between 3 and 10 months; this growth works mainly to mature the cerebellum to facilitate its role in activating and controlling motor actions. If the child does not already have adequate inputs of the kinds sketched above (hugging, singing, and a main caretaker, etc) these new cerebellar connections will build on to a somewhat less than optimal set of functioning networks so the new controls and their functioning will not themselves be optimal.

Consider what occurs when the child doesn't receive enough hugging. Since its functions are almost totally concerned with its own well-being (its egocentricity), it must have a sense that the world out there is friendly and wants it, respects it, even loves it so that it can pay attention to other sensory functions. If not hugged enough, its other functions develop poorly as the child concentrates on seeking to satisfy its need for self-preservation (since there is no protector in contact with the child); this also could be described as satisfying the need for self-esteem. Comer's studies (1980) show clearly that the child needs to be adequately developed psycho-socially before it can begin to pay attention to the instruction being aimed at it by its parents, its teachers, and the school. In other words, unless the child has a positive self-image, it cannot devote enough attention and energy to the acquisition of the external matters that schooling is aimed at conveying. Both the social context and general properties of the environment contribute to what Greenough et al (1987) call the experience-expectant modifications of the brain and behavior. That is, there are genetically-programmed neuroanatomical structures whose organization and functioning are partially to be specified by later external inputs. The reason that this functioning has not been selected for is precisely because it depends on the environment and is therefore being taught to the individual. Language is the most obvious example. Functions that are not already programmed can be learned (or taught) and so are almost never capable of being selected for. This point will reappear in describing all later developments whose structures are not entirely genetically programmed. In addition, it has been shown (Field, 1995) that massage of infants of all species decreases the concentration of stress hormones and leads to improved behaviors.

During the 10 month to 2 year period of slow brain growth, the child practices its entire complement of actions and controls, thereby improving, consolidating, and perfecting them to the extent to which the networks are optimally arranged for those purposes. As the child grows, its control of movements improves with practice and experience so the networks controlling those movements must be being pruned and sharpened so they work more efficiently. If the child is not given enough experience of a wide enough variety to activate its entire spectrum of movements, some of these control networks could be less than optimal. The next large brain growth stage (2 to 4 years) is concerned mainly with the maturation of the senses. Data for vision and hearing(Tschopp et al, 1999; Fisch, 1983)illustrate the documentation of this assertion. The analysis by Geschwind (1965) connects development of touch with those of vision and hearing. It would be interesting to know if the other two senses (taste and smell) are maturing during the same brain growth stage. They are much less studied, but a review of both by Cowart and Beauchamp (1998) cites 2 papers as providing evidence that children are approaching adult smell sensitivity around age 3 years.
Since the child has reached the age of the Vygotsky Fusion of thought and language development, meaning that the child now speaks in concepts and thinks in words (Vygotsky, 1962), language aspects are especially significant. But, the child can see, hear, taste, touch, and smell virtually on the adult level by the end of this stage.

How can a child be deprived? Does the prototypical child in an urban ghetto family see fewer things than the child of a middle class environment? Generally not. Similarly, that ghetto child hears, tastes, smells, and touches as wide a variety as the more fortunate child. Therefore, the ghetto child is not deprived in any of the five senses. But these are the only routes into the brain. Yet, we know that many such children are functionally deprived. Of what can they be deprived? One possibility is in the association of those sensory inputs. If true, then association is the key to the first level of mental functioning. Association at this level means, for one example, being able to infer vision from sound as hearing some metal clanking tells the child that it will see some keys if its choice is between a rubber ball and a key chain. It will be shown later that association is the key to almost all mental functioning. Once again, however, the effectiveness of those newly programmed and trimmed networks is partly affected by and limited by the correctness of the already-formed or underlying networks. So, as before, maturation of the senses themselves is optimal only if the preceding stages were installed optimally.

The 4-6 year slow brain growth period resembles the period between 10 months and 2 years in being occupied mainly in the gaining of experience and expertise in using the existing and the newly-modified networks to perform those sensory and motor activities. Such experiences consolidate those functions.

A main reason why intervention programs like Head Start are so relatively ineffective cognitively (Epstein, 1988; Hood, 1992; Zigler, 1993; Lee, 1995) could be that they are run chiefly during this slow brain growth period. There is some evidence (Campbell and Ramey, 1995)that running intervention programs during the earlier rapid brain growth period would be far more effective cognitively. They have now followed the children out to age 11 years and found persistent cognitive enhancement. The brain growth data indicate that these intervention programs should run from Zero to Four years rather than the presently favored Zero to Three years. Such an extension would also help slower developing students.

As before, individual differences appear due to differences in life experiences up to this point. From the point of view of something like the Piagetian stages, new functions are being acquired and sharpened on a somewhat non-synchronized schedule so that we see the appearance of what are called decalages: the spreading of developmental stages over ages (vertical decalage) and over the parallel domains in which the same functions can be employed (horizontal decalage).

If the individual sensory functions are not optimally programmed, their association will also necessarily be less than optimal. We note that association is again the key component of intelligent behavior at this point in development. Anatomically, the association of the visual, somesthetic, and auditory senses takes place in the inferior parietal lobe (areas 39 and 40) as shown by Geschwind (1965) who termed that lobe as “the association area of association areas”. Geschwind also described its apparent absence in non-humans. He pointed out the study by Weinstein and Teuber (1957) of soldiers who had survived being shot in the head during the Korean War. Comparing their IQs taken after recovery with their pre-induction IQs showed no significant effect of the injury unless the wound affected the inferior parietal lobe; if hit there, their IQ's dropped some 30 points to make them very unintelligent indeed. Up to this stage of development, reasoning then seems to be almost entirely associative.

It is very important to note that synthesis of new brain cells comes to a virtual halt around age 4-5 years (Winick, 1968). Because of sensitivity limitations on the measurements, it is not possible to state that no synthesis at all occurs later. But, as far as can be determined, there is a cessation of activity of the enzyme involved in replicating the DNA (DNA polymerase) and an asymptote in total DNA per brain so there is no significant increase in the number of brain cells.

The importance of this finding is that, because the brain increases about 30% in weight after that age, the additional weight has to be in increased weight per brain cell. Much of the increased weight is in the increased arborization of neurons, meaning they send out longer and more branched axons and dendrites to create functional connections among more distantly located groups of neurons (Conel, 1939-63; Rabinowicz, 1979). This increase in network complexity makes possible and inevitable more complex mental functioning.

Thus, when the next rapid brain growth stage begins around age 6 years, connections are made between already existing neuronal groups that subserve distinct functions. In other words, previously separate mental and sensori-motor functions are now associated, thereby creating more complex functioning. In essence, this results in what might be called abstract sensori-motor capacities as well as concrete reasoning.

The additional brain weight (and its manifestation in new networks) appear on a biological schedule, as shown by the work of Brown (1973) on children of that age, finding that not even very high IQ children begin to manifest the new functions until they reach the typical onset age of about 6 years. The sharpness of the functions being associated is limited by the sharpness with which the components were initially created as discussed above. Thus, their association has corresponding limitations. This means that children who received less than optimal earlier inputs now presumably acquire less than optimal association networks and functions.

Piaget (1969) has shown that the additional functions appearing at this age are those of what he termed concrete reasoning: the ability to reason logically about directly experienced inputs. This makes sense biologically, because the only networks created up to this time are those operating sensori-motor activities.

It is extremely important to point out that these new functions are not genetically programmed because, if they were, virtually all children would manifest those concrete reasoning functions at roughly the same ages, as they do during the earlier brain growth stages when virtually all children manifest the typical motor and sensory functions. This means that the functioning of those augmented networks is dependent on modifications by a combination of inputs from experience and instruction. Their functions have to be learned!

This is the first indication that humans are dependent on instruction for acquisition of the higher cognitive functions. Moreover, humans will remain instruction-dependent for those higher cognitive functions because, as remarked above, those functions can be taught. Therefore, evolution cannot act to acquire and install them in genetic programs any more than dogs can be selected for automatically fetching newspapers. Evolution could act, however, to enhance instructability.

Once again, a period of consolidation of the new functions occurs -here in the slow brain growth period between ages 8 and 10 years. This period has been so minimally studied that it is not unlikely that significant increases in cognitive development can be achieved by finding how to take advantage of the child's abilities at this period.
Starting around age 10 years, the next rapid brain growth stage onsets and, once again, is manifested in significant increases in neuronal arborization, creating additional contacts and associations between the earlier-organized networks and their derivative mental functions. These new networks also appear on a biological schedule, as shown by the work of Webb (1974) on high IQ (>=160) children of that age. None of these high IQ children began to manifest these new functions before the onset age of about 10 years.

This time, however, new contacts can be made between neuronal groups or networks subserving concrete reasoning. This makes possible the association of concrete reasoning functions into generalizations about such functions. In other words, at this stage it becomes possible to manifest what Piaget called formal (or abstract) reasoning which transcends direct experience to deal with the not-directly-observed groupings of those earlier concrete reasoning functions. And, as before, the quality of the new functions is limited by the quality of the networks and functions being associated by the additional arborization.

There are two entirely novel aspects of this rapid brain growth stage. First, unlike earlier stages, this one has a readily observed gender difference. Even though both genders manifest significant new brain growth, females have about twice as much brain weight increase as males. We would expect that females are now capable of developing more, and/or more rapidly, and/or better, and/or different new mental abilities, but there has been no systematic study of what females can do differently from males starting at that age of about 10 years. There are some clues in differential performances on non-verbal sensitivity and on aspects of mathematical reasoning, but they haven't been studied from the point of view of the genders' brain growth difference.

An important clue to the kinds of functions being installed may come from the studies by Thatcher et al (1986) and by LeMay (1977) which indicate a preponderance of right-side brain growth during this stage.

Second, new contacts can be made between concrete functions and sensori-motor functions. Perhaps this is a good time to start some additional inputs to take advantage of consequent cognitively-enhanced motoric potentials. The remarkable athletic capacities of females at these ages may well result from their enhanced brain growth as much as from their physical development. And, as usual, the next slow brain growth period (12-14 years) becomes one of practicing, perfecting, and consolidating the new networks and the mental functions they can subserve.

It is of potentially great significance that the next rapid brain growth stage (14-16 years) is one in which male brain weight increase is more than twice as much as that of the females, with a slight preponderance of left-side brain growth. The additional arborization now has two main kinds of possible new contacts. It can connect previously unconnected concrete reasoning functions so that additional formal reasoning functions are added during this period. Or, it can connect already existing formal reasoning networks (and their functions), permitting a still more complex kind of network and associated mental functioning. This has been termed "post-formal" reasoning by the few persons who have tried to study this situation. Its behavioral description is still so tentative that there are no generalizations available for describing those novel functions.

The period is one with a distinctly greater male growth in mathematical abilities but we don't know whether to assign this to the formal or post-formal kinds of connections. In any event, it is not surprising that there are more male changes because the female brain growth during this period is very much less than that of the males.

As there is no evidence of more brain increase by the criterion of brain weight, this would seem to be the end of the series of reasoning stages. However, Hudspeth and Pribram (1990), after confirming the showing (Epstein, 1980) that EEG stages precisely parallel the brain growth stages, also found indications of another EEG developmental stage between 18 and 20 years. It seems remarkable that this new stage appears "on schedule" in that it fits the pattern that the stages appear every four years: 2-4; 6-8; 10-12; and 14-16 years. Such a coincidence could well be evidence for a set of recurring biological events that could be studied.

An insight needing stressing is that the Piagetian reasoning schemes have been confirmed and reconfirmed many times; they have their earliest onset ages as given by the Piagetians. When others carry out experiments to test whether traces of the various reasoning schemes can be detected at still younger ages, it is quite frequently found that there are such traces, but they use different test items and activities. That kind of finding is not at all incompatible with the validity of the Piaget stages and schemes. If one creates other tests of a child's reasoning ability, and if they are reproduced exactly as was done in the initial work, confirmation will also be found.

What that really means is that any set of reasoning schemes can be used to describe the development of the child. And, if they are studied developmentally, it will be found that there are significant changes in children's capacities starting precisely at the rapid brain growth stage ages. We continue to use the Piagetian schemes because there is far more experience with their determination than with any other set. Moreover, those employing other reasoning schemes/tasks have apparently not payed enough attention to the fact that alternate sets of schemes/tasks would be useful on their own terms.

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