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Developmental neuroscience: implications for early childhood intervention and education

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Summary There has recently been considerable interest in whether findings in developmental neuroscience have implications for 0–8 years early childhood intervention and, education and, if so, what these might be. Findings from five areas are considered: prenatal development, synaptogenesis and synaptic loss, sensitive periods, the effects of complex environments, and neural plasticity. Findings are considered to have implications if they challenge rather than confirm current practice or policy in early childhood intervention and education, or if they challenge knowledge in the field that has been derived from non-neuroscience research. On this basis, findings to date from developmental neuroscience appear, despite their high scientific interest, to have few immediate implications for practice or policy. Some research is confirmatory of non-neuroscience developmental psychology research. Future research in developmental neuroscience may have more implications.

INTRODUCTION

Advances in brain science, particularly within developmental neuroscience, have recently attracted much interest among those concerned with young children's development. Some advocates for early childhood intervention and education have viewed findings from developmental neuroscience as a new and powerful justification for increasing provision. Professionals in education, health, social regeneration and allied fields who have become aware of this research have begun to wonder what implications there might be for their practice. Policy-makers wonder whether service priorities need reconsidering. Yet it is not always clear to those concerned as to what the new science has actually found and how, specifically, it relates to ways in which society supports children's development and learning.

The aims of this paper are to summarize the scope and achievements of developmental neuroscience, identifying key findings and insights of potential interest to practitioners and policy-makers, and then to consider what, if any, implications there are for practice or policy in the field of early childhood intervention and education. This means being clear about how science can hold implications for any field of social action. It is also necessary to consider the current state of the area of early childhood intervention and education, and how it is informed by non-neuroscience developmental research. On this basis, it is possible to reach a view of the present relevance of developmental neuroscience.

DEVELOPMENTAL NEUROSCIENCE: SCOPE AND ACHIEVEMENTS

Developmental neuroscience encompasses a wide range of interdisciplinary research, including clinical and non-clinical human studies and animal studies, at the molecular, cellular, chemical, genetic, physiological, behavioural and cognitive levels. It is not possible to draw definite boundaries around this field of enquiry, nor precisely to date its emergence, but it is characterized by systematic attempts to link our understanding of brain development to a psychological understanding of development and learning. This has been helped by new investigative techniques (such as functional magnetic resonance imaging and positron emission tomography, which, by monitoring small changes in blood flow, make it possible to identify which regions of the brain are implicated in different psychological processes), but many findings derive from established techniques, for example clinical studies of brain damage in humans, animal studies and quantitative

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electron microscopy. Findings in five particular areas have attracted interest.

Prenatal development

Interest in prenatal development of the brain has focused on factors, particularly in the first trimester, that threaten later development. In the USA, a joint report from the National Research Council and Institute of Medicine[1] has identified three categories of factors—infectious disease, neurotoxins and nutrient deficiency—as major concerns. The classic example of an infectious disease is rubella, which can damage the fetus's brain as well as eyes, ears, heart and other organs.

Neurotoxins include lead, tobacco, aluminium and mercury, but one of major concern is alcohol. Fetal alcohol syndrome, estimated to occur at a rate of 1–3 per 1000 live-births, can lead to a loss of neurones, severe neurobehavioural impairment and impaired cognitive functioning, among other problems. Malnutrition has long been known to limit brain size, but, in terms of specific nutrients, a deficiency of iron has been shown to have profound effects on general motor and cognitive functions. This may be due to its role in neurotransmitter synthesis, myelination, oxidative metabolism and memory processes in the hippocampus.

The vulnerability of the developing brain to these early biological insults might be considered to be an issue beyond the concerns of early childhood intervention and education, but there is an increasing recognition that, to succeed educationally, programmes need to integrate health and antenatal interventions with educational interventions.

Synaptogenesis and synaptic loss

Brain development is not so much about the growth of neurones (whose number does not appear to increase greatly after birth) as about the growth of connections between neurones, i.e. synapses. There is evidence that synaptogenesis in the young involves a considerable overproduction of synapses followed by the loss of many of these. This has been shown in the visual system of the cat[2] and the cerebral cortex of rhesus monkeys[3]. In humans, studies by Huttenlocher[4,5] indicate that synaptogenesis, followed by synaptic loss, peaks at different ages in different areas of the brain, for example in the visual cortex at around 6 months and in the prefrontal cortex at around 1 year, the loss continuing until adolescence. The period of rapid synapse formation appears to end around 3 years of age. The reasons for this overproduction and loss are not well understood, but it has been suggested that frequently used connections are strengthened whereas those rarely used are lost and that this kind of synaptogenesis reflects a species-specific expectation of certain experiences such as exposure to light or sounds occurring at certain times in the early years ('experience-expectant' synaptogenesis).[6]

The fact that the production and loss of synapses is taking place in very young children has led, as Bruer[7] has shown, some advocates of early childhood intervention and education to argue that children in the 'zero to three' period need maximum stimulation of all kinds so that as many synapses as possible can be retained. Put colloquially, the argument has been 'Use it or lose it.'

Sensitive periods

In 1965, Weisel and Hubel reported a study[8] in which they deprived newborn kittens of their vision in one eye. After 3 months, the eye was uncovered. It was found that the cat was virtually blind in that eye and that the visual cortex had failed to develop. No recovery of vision was found, and it therefore appeared that the animals had missed a critical period for development.

Subsequent research has led to the term 'critical period' being replaced by 'sensitive period'. The former suggested something irrecoverable, whereas it now appears that, at least in the case of cats deprived of vision, some recovery is possible, depending on the period of deprivation and the extent to which the affected eye is required to be used afterwards.[9,10] In addition, studies of monkeys indicate that what matters for brain development is the nature of the visual deprivation (for example, the disparity in visual experience between the two eyes).[11] The term 'sensitive period' suggests that there may be propitious time windows for certain development to take place but that some later catching up, by one means or another, is possible.

It would be very helpful to know whether there are sensitive periods for the development of cognitive abilities such as language, but what evidence there is on this issue comes from developmental psychology rather than developmental neuroscience.[12]

Effects of environmental complexity

In studies from the 1970s onwards, Greenhough and colleagues have demonstrated that environmental complexity has an influence on brain development in rats.[13] Rats aged 21–25 days were reared in one of three environments: 'isolated' (one rat in a laboratory cage), 'social' (several rats in a cage) and 'complex' (a larger enclosure, including structures, apparatus and obstacles, and shared with other rats). It was known from previous work that rats reared in 'complex' environments were superior in maze learning tasks.[14] After 30 days, the rats' brains were examined. Those which had experienced the 'complex' environment were estimated to have 20–25% more synapses per neurone in the visual area than the others. The brains of those reared in the 'social' environment were not much different from those reared in the 'isolated' environment.

This research has attracted the attention of many advocates of early childhood intervention and education, leading some to imply that 'enriched' environments in the early years can boost brainpower by 25%.[7]

Neural plasticity

Although developmental neuroscience focuses on the young, it should, of course, be informed by findings relating to mature organisms. Without some comparison, there is a danger of assuming that what is found in the young is unique to the young. It is therefore interesting that further work by Greenhough has shown the brains of adult rats also form new synapses in response to new experiences and apparatus.[13] This kind of synaptogenesis, termed 'experience dependent', suggests that the rats' learning need not be confined to a particular period.

There is other evidence of neural plasticity. Nelson[15] reviewed studies of musicians' motor skills, of monkeys 12 years after the deafferentation of their upper limbs, of cortical magnetoencephalography and of adult human amputees, concluding that a reorganization of the adult human brain is possible beyond childhood, not only in sensorimotor pathways, but probably also in cognitive systems. It is also known that specialized adult learning affects observable aspects of brain functioning and structure. Skilled musicians, for example, appear to have an enlarged auditory cortex.[16] London taxi drivers, with their advanced spatial knowledge of the city, have an enlarged posterior hippocampus compared with non-taxi drivers.[17] Neuroscience is revealing brain changes associated with lifelong learning.

Neural plasticity and sensitive periods represent opposing conceptions of development. Complete plasticity would imply that learning can take place at any age and that it is never too late for intervention. Sensitive periods in the early years, however, would imply a crucial role for early intervention and education. Developmental neuroscience provides support for both concepts, and a major task for the future will be to identify the precise learning domains and conditions in which each operates.

THE LOGIC OF IDENTIFYING IMPLICATIONS FOR PRACTICE AND POLICY

Findings from developmental neuroscience are fascinating for anyone concerned with early childhood intervention and education, but 'fascinating' is not the same as 'having implications'. What is needed for scientific findings to have 'implications' for a field of practice?

Findings must be viewed in relation to current practice or policy, which will to some extent be based on non-neuroscience research, including developmental psychology. Take, as an illustration, the Weisel and Hubel findings referred to earlier. It is reasonable to suppose that these findings might have some relevance to the development of vision in children. We might say that if kittens can be so adversely affected by the deprivation of sight in one eye, we should take care to avoid this happening with young children. The difficulty is that this does not really change anything. It is already good practice to intervene as early as possible—surgically if necessary—if young children have congenital cataracts or strabismus. This is because it has been known from clinical practice and non-neuroscience studies that a failure to intervene results in long-term visual deficits.[18] The neuroscience findings do not so much provide implications for changing existing practices as reassurance for maintaining them. It could of course be that practices are not always properly pursued, that child health surveillance is inadequate and so on, but that does not change the fact that health, childcare and education policy-makers and practitioners generally know what *should* be done. The same applies to poorer, developing countries. Children there may not get the intervention they require, but we do not necessarily need developmental neuroscience to tell us they require it.

Findings that do have implications for existing policy/practice are those which challenge what is currently done (or not done). This is a lot to ask of science, but the alternative is to accept that everything remotely relevant has implications. To identify findings that have implications for early childhood intervention and education, it is necessary to know what is currently carried out in the field.

EARLY CHILDHOOD INTERVENTION AND EDUCATION: CURRENT PRACTICE AND POLICY

'Early childhood' generally refers to the period up to around 8 years of age. In most Western industrialized countries, 'what is currently done' in this field includes basic public health provision, varying preschool educational provision and compulsory full-time education (with a starting age varying from 5 to 7 years). Individual children deemed to have 'special needs' usually have access to some additional services, and many countries also have various intervention programmes. In this paper, 'intervention' has a wider meaning than medical intervention to remedy specific childhood disorders or illnesses. Here it refers to programmes intended to enhance child development in relation to a range of educational, health and social outcomes, often directed at young children in disadvantaged communities, i.e. 10–20%, rather than 1–2%, of the population. 'Intervention' has the connotation of doing something different from or extra to what is normally done. It therefore follows that what is an intervention in one context may not be so in another. In countries where schooling begins at the age of 6, for example, starting at 5, as in England, could be regarded as intervention. In the context of England, part-time education for 4-year-olds was once seen as intervention but is now so common as to be simply part of 'early childhood education'. What is intervention in one era can become mainstream in a later one.

Something that does currently count as early childhood intervention in England is Sure Start, a programme aimed at children 0–4 years and their families in disadvantaged communities.[19] It is new, experimental and intended to be additional to mainstream provision, and it may or may not enter the mainstream in the future. Sure Start also exemplifies another—increasingly common—feature of early childhood intervention in that it has clear educational aims relating to learning, language development and school readiness but recognizes that these can only be accomplished by integrating health, social and community services with early childhood education.

Overall, early childhood intervention and education in most Western industrialized countries is a reasonably well-recognized and resourced field of activity, at least in the 5–8 year-old period. Provision for the under-5s is less extensive and more fragmented. Play and exploration are generally valued and certainly so for younger children. Health services dominate earlier in the period, education later, and the two may not be well co-ordinated. Children in disadvantaged circumstances may be targeted for intervention programmes. In countries where provision is undeveloped, there is often an aspiration to move towards the level of services in developed countries.

Throughout its history, practice in early childhood intervention and education has been justified by appeals both to 'common sense' and to science. The former is illustrated by maxims such as 'As the twig is bent, so the tree grows' or 'Give me a child to the age of 7 and I will give you the man.' The latter has involved turning to developmental psychology, particularly behaviourist, Freudian or Piagetian theories and ideas about 'critical periods' in early development. It is to this context that findings from developmental neuroscience have to be related and their possible implications assessed.

WHAT ARE THE IMPLICATIONS FOR PRACTICE AND POLICY?

Since the mid-1990s, there has been an extraordinary upsurge in claims (documented by Bruer) that findings in developmental neuroscience have major implications for early childhood intervention and education. We can review such findings under the five headings used above.

Although not the most widely publicized, findings about *prenatal development* appear to have significant implications. There is a case for targeted antenatal intervention programmes in disadvantaged areas where children are at risk of being born less ready to thrive and learn on account of mothers' illness, poor nutrition and intake of neurotoxins during pregnancy. In England, the Sure Start intervention programme seeks to address this issue.

More than any other findings from developmental neuroscience, those concerning *synaptogenesis and synaptic loss* in the first 3 years of life have generated the most heat. In the USA, the 'Use it or lose it' view has reached what the joint report from the National Research Council and Institute of Medicine[1] described as a 'frenzy of concern'. One can understand parents' awe at being told that their babies are producing an enormous number of synapses and their anxiety at being told that many are lost because they are not used. On the basis of current knowledge, this is, however, experience-expectant synaptogenesis, and babies usually have enough sensorimotor experience to use and retain the synapses needed in later life. One can speculate that if there were additional stimulation, it would result in more synapses being retained and that there could be an overall benefit to children, but there is currently no evidence on this point. Thus, in the context of current practice and policy in early childhood intervention and education, the synaptogenesis findings appear to have no immediate implications.

Early childhood educators have long been attracted by findings concerning *sensitive periods* because of the fit with beliefs, referred to above, that the early years are critical for later development. It is interesting that Weisel and Hubel's study[8] provided one of the earliest examples of research in developmental neuroscience (before the field was named as such) being used to justify policy in early childhood education. In 1967 in England, it was cited by the Plowden Report[20] as one piece of evidence that early learning was critical and that preschool education should be increased, especially for children in disadvantaged areas. What was discounted was the fact that the deprivation studied by Weisel and Hubel was of a completely different order from that experienced by young children (who, whatever their disadvantage, rarely have their eyelids sewn together) and that it involved a very specific brain function. This is either a case of gross overgeneralization (from the visual system in kittens to overall development in children) or a 'metaphorical' use of research findings in the service of policy advocacy; either way, the leap from findings to implication is too far. There may yet be findings from developmental neuroscience about sensitive periods (e.g. relating to language or musical learning) that will have implications, but this is not yet the case.

Findings about the *effects of environmental complexity* have also been very attractive to early childhood educators. Early work in this field actually used the word 'enriched', which resonated with 'enrichment programmes' for disadvantaged children. It would be very nice to think that such programmes improved children's brain development; indeed, they might do, but to conclude that from developmental neuroscience is again to overgeneralize. The 'complex' environment for rats in Greenhough's studies was compared with cage environments that, by the standards of a real-world rat's wild environment, are best described as 'grossly deprived'. The human correlate would be raising babies in bare prison cells. Not only is such deprivation extremely rare in human societies, but, when it is discovered, people's immediate response is to rescue the victims and give them as much care, stimulation and love as possible. They do not need developmental neuroscience to tell them what to do. This finding, despite its scientific interest, therefore currently seems to have no practical implications in the sense of challenging what is currently done.

Finally, there are the findings on *neural plasticity*. These have relevance in showing that development and intervention after early childhood are possible and that programmes in that period need not take all the responsibility for securing the eventual outcome. This is also known from non-neuroscience research, but it is worth having extra encouragement from developmental neuroscience to persist with what may seem very difficult populations, such as children rescued from grossly deprived environments. As much of this research has been carried out with humans in settings close to real life, there is not the danger of overgeneralization that limits the relevance of other findings. Findings suggest that brains go on changing and that abilities never developed or thought to be lost may to some extent develop or recover after the early years.

CONCLUSIONS

Developmental neuroscience has generated some extremely interesting findings about the relationship between children's experiences, learning and development, and their brains. Findings to date have, however, limited implications for early childhood intervention and education in the sense of changing what is currently already done on the basis of non-neuroscience research or custom. There is a case for action, possibly linked to early childhood programmes, to improve nutrition and reduce exposure to neurotoxins in pregnancy. Otherwise, developmental neuroscience findings are generally confirmatory of current thinking in early childhood intervention and education. Developmental neuroscience is, however, developing quickly, and future findings may have considerably more implications.

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