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Educational investment:
Interrelating neuroscientific, educational and economic perspectives

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The neuroscience of "when" we intervene

Executive Summary: Neuroscience evidence is often misunderstood or over-interpreted, giving rise to 'neuromyths' that can influence how educational resources are prioritised. The main 'neuromyth' is that investment in the early years is justified by neuroscientific understanding of "critical" or "sensitive" periods in child development. The report presents a more accurate, evidence-based story, as follows:

- It has been experimentally demonstrated that incorporating neuroscience to an explanation adds to its allure, even when it is irrelevant. Therefore, claims with an alleged basis in neuroscience should be treated with special caution.
- Whilst the early-years are important for development, evidence of sensitive periods is restricted to very early basic processes, such as our diminished ability to distinguish between new speech sounds after 6 months. Neuroscience has not identified later sensitive periods related to curriculum areas or topics within them.
- Brain development is complex, with different regions maturing at different rates. Simplistic models for development can lead to unhelpful conclusions - we should avoid the simple "learning begets learning" justification for early investment which can suggest higher returns from investing in those already advantaged.
- The emerging evidence from neuroscience suggests all childhood is a special time for learning.
- Neuroscience <u>does</u> provide an argument for weighting resources towards the early years, but chiefly in respect of those suffering significant genetic or environmental disadvantage.
- Some types of investment, when targeted, are likely to generate greater return when weighted towards later years, since many types of potentially costly behaviour (e.g. drug-taking) results from an interaction between decision-making (involving neural circuitry still developing in adolescence) and opportunity (governed by greater freedoms for teenagers).

- A recent economic model which takes better account of neuroscience suggests:
  - Early investment is valuable, but most valuable for the <u>most disadvantaged</u> (whether by genes or environment)
  - This does not mean focusing entirely on early years, and <u>the model advises against a radically disproportionate focus</u>
  - Evidence points to the <u>need for follow-up funding</u> for early intervention.
  - The model suggests greater benefit from <u>interventions in adolescence</u> when such investment is focused on "non-cognitive", such as motivation and self-regulation, rather than "cognitive" skills.
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Objectives

This report will

- Consider the now commonly held belief that early is always better

- Relate this belief to fundamental organisational changes in the brain during development.

- Explain the concepts of *critical* and *sensitive* periods in neuroscience, and suggest the need for referring to periods when we are most susceptible to educational learning as *optimal* periods.

- Review the evidence we have for sensitive periods in human development in terms of when we know they occur, and how they may influence development, so cautioning our application of this concept in education.

- Describe how sensitive periods have featured in the justification for a simple model of educational investment that promotes the simple principle of "learning begets learning"

- Explain why the "learning begets learning" approach is too simple

- Describe an improved model with more than one category of cognitive process and its implications for policy, but still emphasising limitations in its scientific basis.

It should be noted that this report appraises how neuroscience is used in arguments involving educational investment, but does not provide a comprehensive review of literature on educational investment arising from other disciplines.

Earlier is often better

There is clear evidence that early educational interventions can provide long-lasting effects into adult life. Multiple studies show higher quality childcare is related to better outcomes in cognitive, language, and social development[1,2]. For example, in the UK, the Effective Provision of Pre-School Education (EPPE) Project showed that, irrespective of level of multiple disadvantage, 'home' children (those who had little or no preschool experience) showed poorer cognitive and social/behavioural outcomes at entry to school and at the end of Year 1 than those who attended pre-school. These 'home' children were more likely to be identified by teachers as having some form of SEN, and by the end of Key stage 1 the attainment gap was still evident for reading and mathematics[3]. The extent to which the quality of provision can predict outcomes later in education can be striking. A recent study of non-relative child care from birth to 4.5 years has shown that higher quality care predicts higher cognitive-academic achievement at age 15, with escalating positive effects at higher levels of quality[4]. The STAR project in Tennessee showed a correlation between the experience of a child's kindergarten teacher and their future adult earnings[5].

Neuroscience and development

Such behavioural evidence does not conflict with our understanding of brain development, since we know this is a period of fundamental organisation at both the neurological and behavioral level and so, in all senses, the first few years have the greatest claim to being the foundation for all future learning[6]. In neuroscience, learning is chiefly explained in terms of changes in how neurons are connected. The vast majority of our lifetime's supply of neurons arrive within 3 months of our conception, but dramatic changes in *connectivity* between these neurons tends to occur in waves throughout childhood. After birth there is a massive increase in synaptogenesis, i.e. there is a huge blossoming of connections, such that the infant's brain is more connected than an adult's. Then follows a wave of synaptic pruning, in which connections are cut back. These changes occur at different rates in different regions of the brain. (We will occasionally refer to different regions of the brain in terms of different "lobes" – see Appendix 1). For example, in some regions of the occipital lobe (associated with vision), the number of connections peaks at about 8-10 months whereas, in parts of the frontal and parietal lobes (associated with many types of reasoning ability), the decline begins around the beginning of puberty, reaching adult levels at around 18 years or later [7].

Sensitive, critical and optimal periods

It has been suggested that these gross changes in connectivity may be linked to periods when we are particularly sensitive to environmental influence[a]. Indeed, we know that early atypical events, such as sensory deprivation, can radically influence outcomes. Similar, but later events usually have considerably less impact. Neuroscience conceptualises early brain development in terms of a progressive restriction of fate, and considers that there are periods in time when the development of a neural circuit can be particularly influenced by the environment. These periods, which vary in different regions of the brain, are usually known as *sensitive periods*. (More strongly, if effects are considered irreversible, they may be called *critical periods*.) A famous example of a sensitive period is our ability to distinguish between speech sounds. We have much greater difficulty in doing this if we have not heard the speech sounds before we are 6 months old[8]. This makes it more difficult to learn a language containing these sounds in adult life. Other influences in the external environment might include all nurture, traumatic events, encounters with common and atypical stimuli, and education. As in the example of early language, however, the existence of a sensitive period does not exclude the possibility of later remediation but learning outside of this period will be more difficult.

Sensitive and critical periods are scientifically derived terms related to our understanding of neural (in the brain) processes (often studied by imaging) and cognitive processes (often measured through special tests of behaviour). Educational learning is often measured through examination success and relies upon a complex involvement of many different neural circuits and cognitive processes. There is, therefore, not likely to be any simple relationship between our understanding of sensitive periods and educational achievement. Despite this, in education, it has been observed that adult expertise in a curriculum area is influenced by the time when learning began and, in areas such as second language learning which relies strongly on perceptual processing, this effect can be quite striking (see Fig.1). This has led to such effects being discussed in terms of a "critical period for second language learning"[9]. However, if sensitive/critical periods play a role in any type of educational learning, it would probably involve the overlap of several such periods in complex fashion. Since it is unwise to hypothesise any mapping between the scientific and educational concepts, it has been suggested[10] that we should refer to periods when we most easily learn educational topics as *optimal periods* for learning, to make clear the theoretical distinction between these and critical/sensitive periods.

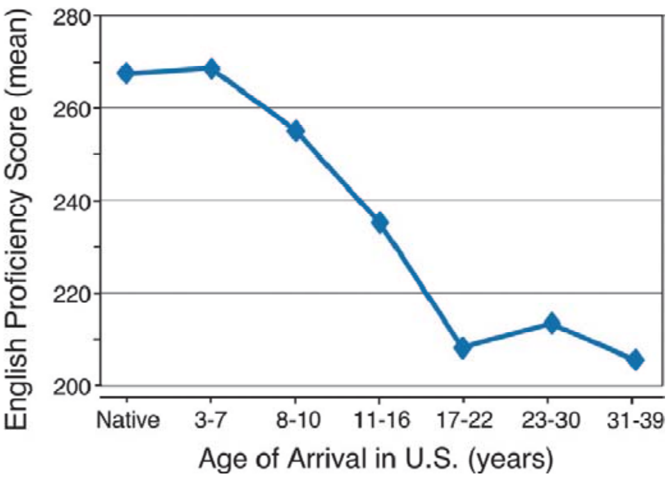

Fig. 1 Second language proficiency with age of acquisition (Johnson, J. S. & Newport, E. L. (1989) *Cognit.Psychol.* **21,** 60–99.)

At the moment, no neural data has been yet derived that supports the notion of sensitive periods in relation to curriculum areas or topics within them[11]. As children travel through the curriculum, the types of processing and reasoning they grapple with become ever more complex, higher-level and formally based. For such learning, we do not currently know enough to use neural arguments to set optimal timings of curriculum.

Known sensitive periods occur very early, but later ones probably exist

While the relationship between sensitive periods and education remains speculative, even the interrelation of neural and cognitive perspectives in this area is still emerging [b]. Evidence for understanding behaviour in terms of the neural mechanisms of sensitive periods is currently restricted to some very fundamental types of processing that develop in the first months of life such as sensory and motor (movement) processing. (Even our previous example of language development refers to the auditory processes of sounds.)

Some scientific studies of sensitive periods have focused on the role of neurotransmitters (chemicals involved with transmitting information across the connections, or synapses, between neurons). From studying the development of sensory and motor processes, the neurotransmitter GABA (gamma-Aminobutyric acid) has been identified as having a key role in the opening and closing of some sensitive periods[12]. For example, in terms of the development of visual regions, scientists have altered GABA circuitry to demonstrate they can cause animals of the same age to peak at different times in their receptiveness to environmental influence (and either before or after their normal sensitive period)[13]. It is worth noting that GABA changes are not restricted to the early years but have been found to occur across the lifespan in the human brain[12]. For such reasons, while only firm evidence exists for neurally-based sensitive periods in the earliest stages of infant development, it has been reasonably hypothesised that these periods may extend further, possibly even into adolescence[14]. Certainly, the significant structural and connectivity changes that occur into early adulthood suggest that all childhood is potentially a special time for learning.

Sensitive periods may help understand abnormal rather than enhanced development

We know that healthy neural development is an important part of the foundations for later learning. To whatever extent sensitive periods are involved in this development, their involvement tends to emphasise the importance of a normal, typical (or “expectable”) environment during these times. Our understanding of the neural processes does not allow us to predict that a developmental trajectory will be enhanced (i.e. beyond the normal profile) by experiencing enriched environments during these periods. The existence of sensitive periods should not be taken as evidence that children with normal genetic and environmental backgrounds can derive the same benefits from early interventions as those from deprived backgrounds[15].

For children suffering from a developmental disorder, there is evidence that their developmental trajectory can diverge significantly from the general population well before schooling begins[16]. Genetic components of developmental disorders point to innate influences contributing to this trajectory[17]. Further evidence for early neural differences derives from measuring event-related changes in the electrical activity produced by the brain (Event-Related Potentials) that can identify newborn infants who will later, at 8 years old, be poor readers or be dyslexic[16]. For these children, early diagnosis and intervention can be very important. A difference in innate influence and/or a very early atypical environment has set them on a trajectory that results in a very early measurable difference in response to ordinary "common" stimuli well before difficulties with formal education. Innate and/or their early environmental experiences have resulted in an inadequate foundation for responding appropriately to mainstream educational programmes, and sensitive period mechanisms may well be involved. When early influences are jeopardising development, early intervention will provide the best chance for ameliorating the differences that would prevent these children reaching their full potential.

The economic return on early interventions is potentially extremely large, given the huge economic costs associated with the developmental disorders. The Dyslexia Institute puts the costs of failure to identify children with specific learning difficulties as high as £1 billion pounds[18]. In addition to lost earnings and greater health problems numerous costs are incurred by, for example, support for children excluded from schools (£50 million[a]) and the excess number of individuals with learning difficulties in prison (£292 million[b]).

In the area of special needs education, it should not be assumed that early intervention will obviate the need for later investment. It is considered unrealistic to think of earlier intervention as an alternative to later intervention when problems have become established: both are needed[19]. However, there are examples where early action has succeeded in preventing the need for later intervention, and the future use of neural markers for the earliest possible identification of risk may further contribute to these successes[20].

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[a] Calculated by the Dyslexia institute thus: 9,290 school children are permanently excluded (DfES figure), 64% of these have special needs, 80% will have dyslexia. Therefore, it is assumed half of permanent exclusions due to difficulties not being identified early, with the cost of provision for each of these excluded children assumed to be £9,900 pa (NFER figure).

[b] Calculated by the Dyslexia institute thus: In 2004, Dyslexia Action reported 20% of 78,000 prisoners in UK had dyslexia and related learning problems: double normal in normal population according to international figures. Therefore, assuming 10% of offenders might have been prevented from crime by early intervention, and cost of keeping an individual in prison as £37,500, such intervention offers a potential saving of £292m pa.

The concept of the "sensitive period" and the "learning begets learning" model of investment

We have seen that those sensitive periods that have already been identified are restricted to very primary functions and chiefly involve sensory and motor processes. However, such primary processes can support the acquisition of higher order learning processes, and so problems here can interfere with a wider range of later learning processes. In this way, sensitive periods appear to provide evidence for a simple "learning begets learning" model for understanding individual trajectories.

Nevertheless, despite the difficulties in relating learning in curriculum areas with sensitive periods as discussed above, such ideas have featured in arguments that emphasise why earlier is generally better in educational contexts. These arguments, directly or otherwise, usually promote the "learning begets learning" principle, based on the idea that opportunities for influencing foundational neural circuitry all begin very early and then face the same rate of decline for all aspects of cognition and in all regions of the brain.

Such an approach can be used to formally model the effectiveness of investments at different stages of childhood. Heckman's original theory of skill formation did not differentiate between different types of skill, but central to the analysis was the concept that childhood has more than one stage. Skill formation is a life cycle process. It starts in the womb and goes on throughout life. Heckman and colleagues reasoned that skill attainment at one stage of the life cycle raises skill attainment at later stages of the life cycle (self-productivity). Furthermore, early investment facilitates the productivity of later investment (complementarity). These two factors combine in the model such that, as Cunha and Heckman state "skills beget skills and abilities beget abilities"[21]. Their original simple model makes two important predictions: that early investment should be followed up by later investment in order for the early investment to be productive (which is supported by behavioural evidence[19]) and that, all else being equal, the earlier in life that investments are made, the greater the economic return.

The simple "learning begets learning" model can lead to neuromyths of "hot-housing" and equity/efficiency policy dilemmas

The simple "learning begets learning" model can lead to ideas that appear to be based on science (i.e. because they draw on concepts such as the sensitive period) but are actually myths. One of these myths is the idea that neuroscience supports the value of immersing young children in environments that are rich in stimulus in order to boost their brain development. Apart from alluding to concepts of sensitive periods and synaptogenesis (see note a), attempts are sometimes made to support this assertion with more direct evidence from neuroscience. For example, it has been found that rats form greater numbers of neural connections when living in cages "enriched" with stimulus than when living in empty cages. However, since these enriched environments more closely resemble the rats' natural level of environment than the empty cage, such experiments only demonstrate the importance of avoiding deprivation, rather than suggest ways of receiving atypical enrichment. In a similar[c] way, the economics literature places heavy emphasis on evidence that interventions such as the Perry Preschool and Abecedarian Programs improved the long-term outcomes of children by enriching their early environments[22]. But again, the children involved in these studies were from deprived low-income backgrounds. If sensitive periods have a played a role here, it is not clear that similar gains would result from similar investment in children from more "normal" backgrounds.

Models of investment based on “more begets more” also appear to explain how a higher skill base at 3 years old will enhance the productivity of later investment. A model of this type suggested by Heckman emphasises the importance of early investment to ensure that skill base, but it also suggests that investing later in children who have already become disadvantaged by their early years experience may not make economic sense, i.e. that perpetuating inequality is optimal in economic terms[23]. Indeed, when such a model is used to simulate a social planning situation, it is clear that greater returns are provided by investing in those already advantaged[24]. A simple interpretation of evidence from neuroscience and other sources that “more begets more” can lead to a policy dilemma involving a conflict of efficiency and equality. In harsh economic terms, Heckman states “When the initial base is substantially compromised, so are the returns to later investment”[22]. It is important, therefore, to scrutinise this model carefully, because it can lead to popular but misleading ideas about early childcare, and to ideas about return on investment that are problematic in ethical terms. (Also, it is has been experimentally demonstrated that including neuroscience in an explanation adds to its attractiveness, irrespective of its relevance[25]. This makes it particularly important that arguments involving neuroscience are carefully examined.)

The “learning begets learning” model is too simple

The scientific evidence suggests a “learning begets learning” justification for providing the earliest intervention for all learners is too simple, because

i) We have seen that the neural concept of the sensitive period emphasises the value of avoiding an atypical environment, but may not predict the same advantage again when normal development encounters an enriched environment. Therefore, outcomes are not likely to arise simply from the history of investment in an individual’s “skill stocks”, but may depend critically on the extent to which their development, and the influences upon it, can be characterised as normal.

ii) Human development and learning is not continuous. The development of neural networks is not well compared to the growth of a tree in which separate branches are all equally served by a single trunk. Instead, we have different, but interrelated, neural circuits developing at different rates and in different ways until early adulthood. Given the structural changes that continue to occur through adolescence, and associated discontinuous development of some cognitive functions, it is entirely possible that some sensitive periods begin in later childhood.

iii) Some types of learning are not amenable to the earliest intervention. Progress in some important areas will requires individuals to have reached a level of maturity in terms of understanding and decision-making, and both behavioural and neurocognitive research suggests such development continues across adolescence. Some of this development is associated with the type of self-regulation that benefits academic success, but it can also pertain to contexts where external constraints additionally apply. That is, successful intervention in these areas may also rely on individuals being at, or close to, an age when they are granted the responsibility and/or opportunity to rehearse the appropriate judgement (e.g. traffic safety when cycling, sexual relationships and contraception, use of alcohol, etc.).

These factors can all be illustrated in the following example. Imagine we wish to make an intervention aimed at improving the ability of normally developing children to take appropriate risks when they later become young adults. When should such an intervention take place? The simple "learning begets learning" approach might suggest the earliest intervention. We must remember, however, that these individuals are already assumed to have typical development derived from an expectable environment and normal genetic background. Therefore, early interventions, although potentially having greater effect than a later one, may not show such drastic benefit as for those whose trajectory is expected to develop abnormally. Secondly, risk evaluation is an area that may suffer discontinuous development: there is evidence that teenagers have more difficulty in making appropriate decisions than either their older or younger counterparts[27,28]. This suggests that adolescence may be an important time for learning about risk and, more speculatively, that one or more sensitive periods related to risk evaluation may open after early childhood (although note, as yet, we lack firm evidence for this). This presents a biological argument why the earliest intervention may not be appropriate. Thirdly, of course, in the contexts encountered in adolescence and with the increasing freedoms that teenagers enjoy, decision-making tendencies can have much greater consequences than those of younger children (e.g. regarding sex and drugs). Interventions in their earliest years cannot fully incorporate these important contexts. Clearly, in this case, the earliest possible intervention may not be appropriate.

The neuroscientific basis of an investment model critically impacts on its policy implications

In later work, Cunha and Heckman (2010) produce a more sophisticated model by considering two sets of mental skills: cognitive and noncognitive skills, and fit this model to existing behavioural data. The term "cognitive" is used by researchers Cunha and Heckman to mean factors such as IQ and achievement tests, while "noncognitive" is used to refer to factors sometimes considered as personality traits, such as motivation, socioemotional regulation, time preference, personality factors, and the ability to work with others[22]. This division lacks scientific sophistication[d], but it helps illustrate an important point: the scientific basis of a model can have a critical impact on the policy implications it generates.

We saw above that a model that lumps all cognitive skills into a single category can suggest greater economic returns from investing in children who have been advantaged rather than disadvantaged by their early experiences, and this model might also discourage investment in later periods of childhood. Cunha et al.'s recent work reveals this as a "misleading guide to public policy"[24]. In contrast, their new model suggests that the optimal timing of interventions for disadvantaged children depends on the conditions of disadvantage and the desired focus of the intervention. They believe strategies should be targeted to take account of the types of skills involved (although categorised only as cognitive or noncognitive in their model). Their fitted model suggests it is more difficult for investments to compensate for the effects of adverse developmental influence when they are made at later rather than at earlier ages. However, the optimal early-to-late weighting of investment is considerably less when seeking to remediate noncognitive skills rather than cognitive skills. This does not conflict with the views of those neuroscientists who argue that adolescence may also be a sensitive time for learning, especially since these researchers suggest such sensitivity may include social learning processes[14] (i.e., of a type related to Heckman's noncognitive processes).

Cunha et al. use their model to consider two specific types of outcome: educational attainment and crime. For the most disadvantaged, Cunha et al. suggest the optimal policy for maximising educational outcome is to weight investment towards the early years, with crime reduction benefiting more from later investment. Note that the advice is a preferential weighting, and does not suggest focusing entirely on the early years. Indeed, in this sense, the model advises against a radically disproportionate focus. Moreover, the ratio of optimal early-to-late investment greatly declines with advantage, i.e. optimal investment for more advantaged children is less about weighting investment towards the early years. Such a result is convergent with notions of early sensitive periods as discussed above, i.e. periods during which development is particularly vulnerable to not receiving typical environmental stimulus, rather than particular sensitivity to enhanced development from enriched environmental stimulus. The result also counters the idea that the early years provide hot-housing opportunities for advantaged children to gain special enhancement of their potential. To maximise returns, the model suggests optimal early investment involves favouring the deprived, with optimal later investment only slightly tilted towards the more advantaged.

It should also be noted that this work does not attempt to calculate returns in financial terms, but to predict outcome in terms of human skill formation that is considered of economic benefit. There is no simple relation between this outcome and its economic consequences. For example, due to the increased independence and physical capabilities of teenage children, it is possible that small, unfortunate but normal features of developmental trajectory (e.g. increased risk taking) can have very costly consequences (e.g. pregnancy[29], smoking[30], addiction[31]). These aspects of behaviour are amenable to cost-effective intervention. So, it seems likely that comparable gains (in terms of economic benefit-cost ratio) can be achieved by well-targeted and well-designed interventions in later years, as they can in early years. Of course, even in much later life, targeted educational interventions may still offer significant economic benefits. For example, computer-based cognitive training is seen as a promising therapy to maintain brain health and reduce risk of dementia[32], a disease which incurs direct costs to the NHS and Social Care of £8.2 billion annually[33], and up to £17 billion when indirect costs such as the lost earnings of carers are included[34].

Conclusions

In the future, our understanding from neuroscience about sensitive periods may form an important part of explaining why earlier educational interventions are often better, at least in cases of abnormal development. However, what we presently know about sensitive periods is restricted to the very early development of very primary processes, and we have not yet identified later sensitive periods related to curriculum areas or topics within them. Should such periods be identified, their relationship to educational learning will be complex, since this type of learning involves many interrelated cognitive processes.

Sensitive periods have chiefly been studied in the context of abnormal development in response to atypical stimulus. Despite this, they have been used to promote the enhancing effects of enriched environments on normally developing children, as well as to justify models of educational investment that explore outcomes across the ability spectrum. These attempts to integrate neuroscience into economic models of investment began with a very general "learning begets learning" approach that also failed to differentiate between different types of skill/ability. Even so, it appears to generate support for some important principles reflected in the behavioural data, such as the general effectiveness of early intervention and the need for follow-up funding when investing in the disadvantaged. However, the weakness of the model's scientific basis should be noted, especially since it can imply an equity/efficiency trade-off in which economic benefit is derived from investing early in those more advantaged.

The most recent model attempts to distinguish between (two) types of ability/skill. When fitted to existing behavioural data, it suggests that investment should be weighted towards the early years, with greatest benefit from early investment in the disadvantaged. It also suggests that interventions in adolescence benefit more when from a focus on "non-cognitive" skills, such as motivation and self-regulation, rather than "cognitive" skills. This demonstrates how the scientific basis for a model can critically influence its policy implications. However, even these results should be treated with the utmost caution, since the scientific principles upon which the model rests remain very primitive and open to criticism.

Economic modelling of educational investment may soon become more useful as it incorporates evidence, including from neuroscience, in more appropriate ways. Existing examples of such work emphasise that the questions of "when" and "who" are very interconnected with the question of "what" abilities are being targeted, as well as with our increasing understanding of the developing brain.

Notes

[a] The potential link between synaptic proliferation/pruning and sensitive periods has sometimes been used to promote the need for highly enriched environments until 3 yrs old (see also misunderstandings about sensitive periods and enhancing normal development – later in the text). However, modern understanding that these changes continue until late teens undermines this "myth of 3". See also the section "Sensitive periods may help understand abnormal rather than enhanced development" to understand the difficulties with using sensitive periods to promote this myth.

[b] The relationship between neural and cognitive processes is the chief focus of the field referred to a Cognitive Neuroscience.

[c] "Similar" is being used here in the sense that, in both cases, a similar argument can be applied for suggesting normal conditions/influences are being compared with those that are less favourable than normal. It is not possible to say that the extent of deprivation was similar. It seems reasonable to suggest that the conditions experienced by many of the disadvantaged children might have failed to provide an "expectable" environment in the developmental sense, but identifying these children would be very difficult since the limits of what constitutes an expectable environment for human development are not clearly defined.

[d] The cognitive/non-cognitive division used here is primitive and potentially confusing, since few aspects of human behavior are devoid of cognition[35]. Also, attempts to justify the division are not well founded on scientific understanding. For example, these attempts include associating greater malleability in these "noncognitive" skills (relative to cognitive skills) during adolescence with lag in adolescent prefrontal brain development. Yet the prefrontal cortex is associated with a range of executive functions (such as working memory and higher level reasoning) that fall under the classification of "cognitive" skills. Arguments made in the economic literature[36] for this division also point to claims[37] (also situated in this body of literature) that it hard to change IQ after 10 years old. However, the scientific literature does not support this limitation[38], with recent examples of IQ being raised by modest interventions involving young adults[39,40]. Indeed, in a very recent study of training executive switching function in three age groups (mean ages 9,22 and 69 years), similar and significant transferable improvements were found in all three groups.

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Appendix 1 Lobes of the Brain

In humans, the forebrain has evolved to be largest part of the human brain and this includes the *cortex* (outermost sheet of neural tissue). This part of the brain is often described in terms of two cortical hemispheres, left and right, further divided into four *lobes*: the *frontal*, *parietal*, *occipital* and *temporal:*