Encyclopedia on Early Childhood Development

Interactions Between Brain Maturation and Experience in Driving Behavioural Development

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Introduction

Childhood is a time when the brain undergoes significant change. Intuitively, many people would expect brain development to involve linear increases in size with age. However, this is not the case. Brain development encompasses individual developmental trajectories for different brain areas, with both increases and decreases in size over time. For example, cortical gray matter typically shows a peak in volume during adolescence, whereas white matter continues to show linear increases in volume over this period. The age at which the peak thickness occurs varies across the cortex, with *cortical regions* supporting primary functions, such as motor and sensory systems, maturing first and higher-order association areas, such as the *prefrontal cortex* maturing last.[1] Subcortical structures that are *phylogenetically* older than cortex also show differential developmental trajectories. For example, *striatum* shows peak volume in middle childhood.[2] *Magnetic Resonance Imaging (MRI)* lacks the spatial resolution to inform us on what the cellular underpinnings of these volumetric changes are, but some have speculated that they may reflect events at the neural level, such as increases in the number of connections between brain areas and the pruning of underused connections and nerve cells.[3]

To understand the role of brain maturation in behavioural development, it is key to relate these anatomical changes to changes in behaviour. For example, peak volumes of striatum may be linked to sensitive periods for motor learning, as these also occur in middle childhood.[2] Such temporal coincidences between brain and behavioural maturation make it tempting to conclude that there are causal relationships between brain and behavioural development. Such conclusions are supported by reports of correlations between developmental changes in the brain and cognitive measures, where these relationships hold across individuals. For example, Sowell and colleagues[4] showed an association between prefrontal lobe structural maturation and memory function. Similar associations have been reported between prefrontal volume and measures of behavioural control.[5] While such studies do suggest that functional changes in the brain during development are reflected in anatomical changes, they do not inform us of the directionality or causality of such relationships. What is driving the correlation between brain structure and function? In addition to using MRI to investigate brain structure, *functional Magnetic Resonance Imaging (fMRI)* techniques are now available that allow investigators to study brain activity during cognitive tasks or rest. Activity is usually assessed by contrasting a baseline condition with a task condition of interest.

Subject

Understanding brain development ? and in particular its relationship to behavioural development ? is important for constraining our understanding of what children are capable of at different stages of development. For example, the protracted development of prefrontal cortex has been linked to relatively protracted development of behavioural control, whereas subcortical areas in striatum mature more rapidly. This may be related to impulsive and reward-seeking behaviour in adolescence.[6] Furthermore, understanding typical brain development is relevant to understanding developmental changes from typical in child neuropsychiatric disorders, such as attention-deficit hyperactivity disorder (ADHD). Here, imaging studies have consistently suggested that changes in cognition are related to changes in volume and activity of prefrontal cortex, related to poor development of behavioural control.[7] Furthermore, it has been suggested that the attenuation of ADHD symptoms with development in some affected individuals may be related in to normalization of cortical development in key areas.[8]

Problem

Perhaps the biggest challenge in studying brain development is addressing what is driving it. While clearly there is an interaction between environmental factors (e.g., learning and experience) and changes in brain structure and functioning, it is hard to tease these interactions apart. This represents a classic chicken-and-egg problem in whether it is brain maturation that supports behavioural development or whether the brain is maturing under the influence of cumulative behavioural experience. Currently, most investigators would probably argue that it is both. However, to be able to provide a comprehensive answer and to understand the mechanisms at work, we need to tease these processes apart.

Research Context

This question is being addressed by several research groups worldwide, often using non-invasive imaging techniques, such as MRI. This technique can be used to produce structural images of the brain for anatomical studies, where the size or shape of brain areas can be assessed. In fMRI, blood oxygenation level is assessed allowing for an in-vivo measure of brain activity. A relatively new Magnetic Resonance (MR) technique that is being used increasingly is *Diffusion Tensor Imaging (DTI)*. This technique can detect changes in white matter microstructure based on properties of diffusion of water in the brain.[9] All three of these MR techniques are particularly suited to studying development and/or effects of experience on the brain, as they are noninvasive. Individuals can be scanned repeatedly in the course of several days or several years, allowing for tracking of brain changes over time.

Key Research Question

The key research question in this area is how experience and brain maturation interact in driving behavioural development.

Recent Research Results

One example of how imaging techniques can be applied to linking brain maturation to behaviour in development comes from Galvan and colleagues. They took a correlational approach to investigating reward-seeking behaviour in adolescence using functional imaging. This behaviour is supported by structures in striatum (notably the *nucleus accumbens*) that are controlled by top-down prefrontal systems. Striatum is phylogenetically older and shows a developmental peak volume around age 7 years, while prefrontal cortex is known to develop relatively late, with a peak volume at the end of adolescence/early adulthood. In adolescents, the earlier maturing striatum showed a pattern of activation similar to adults, whereas later maturing prefrontal regions looked more similar to children, suggesting that increased reward-seeking behaviour in adolescence is related to differential developmental trajectories of the regions underling this behaviour.[10] While this example informs us of how brain and behavioural maturation go together, it does not yet address how experience comes to play in these processes.

A recent example of the impact of experience-driven learning in adulthood comes from Klingberg. It is established that working memory is supported by the *frontal-parietal cortical network*.[11] Recently, these authors showed that ? in addition to changes in cortical structure ? working memory training is associated with changes at a molecular level: Training changed the binding of dopamine (a neurotransmitter that modulates working memory) to its receptors in key cortical areas.[12] Such findings are exciting as they hold the promise of informing us on how changes at an anatomical level seen using MRI are supported at the molecular level. However, further technical advances are needed before such effects can be investigated in development: Dopamine receptors cannot yet be visualized using MR techniques. Therefore studies such as this one make use of radioactive *ligands* (in this case, one that binds to the relevant dopamine receptor), meaning that they cannot be conducted with children and that the number of scans that can be collected within a given time frame is limited.

Research Gaps

The interplay between brain and behavioural development is a topic of interest and much progress has been made in recent years. However, much of this work has been based on cross-sectional comparisons of individuals at different ages. There is a relative lack of longitudinal imaging studies addressing brain changes within individuals, although this is being addressed by a number of comprehensive studies worldwide (see[13] for a review). One exception is the work by Giedd, Rapoport and colleagues at the National Institute of Mental Health. This group has collected thousands of longitudinal anatomical MRI-scans from both typically and not-typically developing children and adolescents.[14] Furthermore, there has been significant progress on experience-driven brain changes in adults. However, relatively little work has addressed the interplay between experience and brain maturation directly by using imaging techniques in training studies in developing children.

Conclusions

The interactions between experience-driven changes and maturational changes in brain development are complex. Brain maturation is characterized by both progressive and regressive events and these changes are related to changes seen at the behavioural level. However, to date these relationships have often been classified using correlations. While this can inform us on the relationship between brain and behaviour indirectly, it does not provide information on the directionality of these relationships: Is brain maturation driving behavioural development or is it the reverse? Or is it more complex, with each driving the other? While initiatives to investigate childhood brain development within the same individuals are underway, few studies have yet addressed the impact of experience on these changes. As such, our understanding of the relationship between these various aspects of development is still incomplete.

Implications for Parents, Services and Policy

Brain development is an ongoing process that continues throughout childhood and adolescence. It is likely driven by innate factors and by experience. Furthermore, the reverse also appears to be true: brain maturation drives experience and the impact that experiences have on the developing child. However, the mechanisms by which this occurs are not fully understood. Nor is it established whether they apply equally at all stages of development. Research efforts using neuroimaging techniques are addressing trajectories of brain development in typical and atypical populations. Similarly, work with adult samples is addressing how experience shapes the brain. However, work investigating the impact of experience on brain maturation during development and vice versa is still scarce. One important implication of this is that generalizations from work in adults and on typical brain maturation should be viewed with caution, as the full complexity of the issue cannot yet be understood.

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