GENERAL BRAIN FINDINGS

Development of the teenage brain

This article reviews recent research on adolescent brain development. Cumulatively, studies show that ‘the human brain may be adaptive to the behaviorally demanding social environment during adolescence’ (Choudhury, Charman & Blakemore, 2008, p. 142). The focus on adolescents for research is of increasing importance because of the higher rates of psychiatric disorders which can surface in this period. ‘Although adolescence presents a period of maturation in terms of cognitive control, reaction speed, reasoning, and decision-making skills, compared with childhood, it also marks a period of increased rates of depression, substance abuse, suicide, eating disorders, and other risky behaviors’ (Choudhury, Charman & Blakemore, 2008, p. 142).

Neurological studies on the adolescent brain have found that:

• The brain areas that undergo pronounced development during adolescence, in particular the medial pre-fronatal cortex and the parietotemporal cortex, form parts of the “social brain”, that is, the network of brain regions involved in understanding other people.

• There is a steady linear increase in white matter in certain brain regions during childhood and adolescence. This change has been highlighted both in frontal and in temporoparietal regions.

• Behavioral and functional imaging studies consistently demonstrate maturation in executive functions during adolescence. These studies show improvements with age in reaction speeds, accuracy, and changes in functional activation, in associated frontal regions of the brain, in tasks that involve attentional control, cognitive flexibility, and problem solving.

• There is some indication that for face processing tasks, activity in the frontal cortex increases between childhood and adolescence and then decreases between adolescence and adulthood.

• There is a peak in activity within the prefrontal cortex during early adolescence. (Choudhury, Charman & Blakemore, 2008)

The researchers concluded that overall ‘there are two main changes with puberty. First, there is an increase in axonal myelination, which increases transmission speed. Second, there is a gradual decrease in synaptic density, indicating significant pruning of connections. These neural changes make it likely that cognitive abilities relying on the frontal cortex, such as executive functions and social-cognitive abilities, also change during adolescence’ (Choudhury, Charman & Blakemore, 2008, p. 142).

Mobile phone use and cognitive function in young adolescents

There has been increasing concern about the potential adverse health effects of exposure to radio frequency (RF) among children and adolescents who use mobile phones. The focus of much research is on how RF exposure affects the developing brain of children and adolescents. There is ‘now sufficient experimental evidence that mobile phone exposure does alter brain activity in young adults’ and children (Abramson et al, 2009, p. 679).

This study was part of a larger piece of research; the Mobile Radiofrequency Phone Exposed Users’ Study (MoRPhEUS). ‘The aims were: to assess exposure to mobile telephones in secondary school students, and to determine whether there were any associations between this exposure and cognitive function’ (Abramson et al, 2009, p. 679).

Secondary students from a range of Melbourne schools were selected for the study; 317 boys and girls aged between 11-14 years old. Questionnaires were completed by participants and their parents. Cognitive function was assessed with a computerised psychometric test which assessed signal detection, working memory, associative learning and movement estimation. The Stroop colour-word test was also employed.

94% of the children had used a mobile phone and 77% had their own mobile phones. It was found that ‘students who reported making or receiving more voice or SMS calls per week, and in particular more of both, demonstrated shorter response times on learning tasks, but less accurate working memory. Consistent with this, those who reported making or receiving more voice calls per week also exhibited poorer inhibitory function’ (Abramson et al, 2009, p. 683). The completion time for Stroop word naming tasks was longer for those reporting more mobile phone voice calls. Greater mobile phone use was also related to faster reaction times on the simple and associative learning tasks. ‘The findings were similar for total short message service (SMS) messages per week, suggesting these cognitive changes were unlikely due to radiofrequency (RF) exposure. Overall, mobile phone use was associated with faster and less accurate responding to higher level cognitive tasks’ (Abramson et al, 2009, p. 678).

These results suggest that mobile phone use affects the impulsive responsive style of children; the tendency for children to respond before they know the correct answer. ‘Children who used mobile phones more were faster but less accurate on a number of tasks, suggesting that they may be more impulsive than other children, favouring a quick, and not accurate, solution’ (Abramson et al, 2009, p. 683).

BRAIN SEX DIMORPHISM

Sexual dimorphism of brain development during childhood and adolescence

Sexual dimorphism (physical differences between males and females) in the brain is an area of ongoing interest to researchers. ‘Human total brain size is consistently reported to be 8–10% larger in males, although consensus on regionally specific differences is weak’ (Lenroot et al, 2007, p. 1065) This large-scale, longitudinal study used trajectories of male and female brain development. A total of 829 Magnetic Resonance Imaging (MRI) brain scans from healthy children and adolescents (aged 3 to 27 years) were analysed.

Sex differences in the brain were found to be age dependent. There are ‘robust male/female differences in the shapes of trajectories, with total cerebral volume peaking at age 10.5 in females and 14.5 in males. White matter increases throughout the 24-year age period, with males having a steeper rate of increase during adolescence. Both cortical and subcortical gray matter trajectories follow an inverted U shaped path with peak sizes 1 to 2 years earlier in females’ (Lenroot et al, 2007, p. 1065).

The researchers reiterated that ‘differences in brain size between males and females should not be interpreted as implying any sort of functional advantage or disadvantage’ (Lenroot et al, 2007, p.1072).

Sex differences in the adolescent brain

This article reviews the current data regarding sex differences in brain structure and function during adolescence. Adolescence is a particular period of interest because of the ‘increased divergence between males and females in physical characteristics, behavior and risk for psychopathology’ (Lenroot & Giedd, 2010, p. 46).

Studies have demonstrated that:

• Male brains are 9-12% greater in size than female brains.

• There are specific areas of the brain which show differences in male and female adolescents and adults; these areas mostly contain significant populations of sex steroid receptors. Overall, there is some consistency between regions of the brain with structural sexual dimorphism and those found to have high numbers of sex steroid receptors.

• The regions most frequently reported by imaging studies as showing morphological sex differences include the basal ganglia, hippocampus, amygdala and limbic structures.

• Sex differences in white matter development during adolescence.

• Sex steroids continue to have organisational effects on brain structure during puberty.

• Functional imaging studies have shown different patterns of brain activation without differences in performance, suggesting male and female brains may use slightly different strategies for achieving similar cognitive abilities.

• Brain activation levels change as a function of menstrual phase. The relation to cognitive function also may change. Several studies have found that performance and brain activation fluctuate across the menstrual cycle on tasks including spatial ability and semantic performance. Tests of learning and memory also show fluctuations across the menstrual cycle, suggesting that temporary changes in sex steroid exposure can affect neuronal plasticity.

• Prior to the onset of puberty, males and females have approximately equal rates of depression at 5%. With the onset of puberty, rates in females double, while males stay approximately the same. Studies indicate that the increase in incidence of depression is linked to pubertal maturation rather than increases in chronological age.
• Schizophrenia is another disorder whose incidence rises markedly during adolescence and whose presentation shows significant sex differences. Although schizophrenia is slightly more common in males, they have a distinct peak age of onset during late adolescence and young adulthood, while the peak in females is later and more gradual, and there is a second rise in incidence around the time of menopause.

• Longitudinal studies have shown sex differences in the trajectory of brain development, with females reaching peak values of brain volumes earlier than males.

• The complexities of comparing brain measurements in cross-sectional data across development are highlighted by findings in the hippocampus and the corpus callosum, in which studies done at different ages have found different patterns of sex differences. If brain regions are growing at different rates, the size or even direction of the difference between them could depend on the age at which measurements are made.

   (Lenroot & Giedd, 2010)

‘Although a better understanding of how sex differences develop during childhood and adolescence may eventually help to guide interventions such as treatment and education, it should be remembered that all the findings discussed in this paper represent group averages with substantial overlap between groups. Causality has not yet been established between any normal variation of brain development and functional ability. Neuroimaging findings should be taken as clues pointing us towards different processes affecting male and female brain development rather than definitive statements about the capabilities of male or female individuals’ (Lenroot & Giedd, 2010, p. 53).

Brain sex differences and the impact of steroid hormones

The effect of sexual maturation on brain morphometry was explored in normally developing children and adolescents. ‘Sexual dimorphism of brain structures may be related to sex chromosomes, hormonal effects, environmental effects, or a combination of these factors’ (Neufang et al., 2009, p. 470). ‘Behavioral transformations are closely related to cerebral development, encompassing dramatic and widespread changes in brain morphology. Although basic developmental processes are comparable between boys and girls…sexual dimorphisms have been reported for global and regional brain volumes and the time course of brain development’ (Neufang et al., 2009, p. 464).

46 children between the ages of 8 and 15 years were subjects in this neuro-developmental study. Blood samples for hormonal analysis, and MRI imaging techniques were utilised for the data collection.

Typical sex differences were found: ‘males had larger GM (grey matter) volumes in the left amygdala, whereas females had larger right striatal and bilateral hippocampal GM volumes than males’ (Neufang et al., 2009, p. 464). The data suggested ‘that GM development in certain brain regions is associated with sexual maturation and that pubertal hormones might have organizational effects on the developing human brain’ (Neufang et al., 2009, p. 464).

Sexual dimorphism is already present, to a degree, in the neonatal brain. However, ‘many sex differences in brain structures seem to occur after the age of 9 or 10’ (Neufang et al., 2009, p. 464). This study ‘directly linked pubertal stages and hormonal data to brain morphometry in normally developing children and adolescents’ (Neufang et al., 2009, p. 472).

The researchers suggested that ‘one challenge for developmental neuroscience is to identify which aspects of adolescent brain development are related to hormone levels and which are not…and to understand the behavioral consequences of steroid dependent organization and activation of the adolescent brain’ (Neufang et al., 2009, p. 465).

Gender, language and the brain

This article critically examines biological explanations for male-female differences, particularly as they are applied to linguistic behaviour. Cameron (2009, p. 1) notes that ‘there has been a striking shift in both academic and popular discourse’ on the subject of sexual dimorphism. The research on language and gender is systematically analysed in Cameron’s critique.

Two large-scale generalisations about gender and language are noted:

(a) ‘That one sex (in most versions of the argument females, but in some versions males) is innately endowed with superior verbal abilities and a greater predisposition towards verbal communication.

(b) That the two sexes differ in their typical modes of verbal interaction: men favour more competitive speech styles and genres, while women are more co-operative, empathetic, and nurturant’ (Cameron, 2009, p. 5).

Cameron disputes these claims and shows that ‘the generalizations themselves and the conclusions drawn from them are questionable: they are based on a very selective reading of the evidence, and in some instances also on linguistically naive or tendentious interpretations of it’ (Cameron, 2009, p. 5).

“Systematic studies using a variety of methods and measures overwhelmingly contradict the notion [that modern women are more talkative than men], showing that in informal peer-interaction there is typically no sex/gender difference, while in formal and status-marked situations it is most commonly men who talk more’ (Cameron, 2009, p. 6). Furthermore, researchers have also raised doubts ‘about the strength of the modern psycholinguistic evidence for female verbal superiority, pointing out that meta-analytic studies have found the overall effect of sex/gender to be slight’ (Cameron, 2009, p. 8).

‘Recent advances in the study of the brain (especially the advent of new imaging techniques) have produced a wealth of new data, but it has not necessarily become easier to draw clear conclusions from it: studies have proliferated, but their findings are very mixed’ (Cameron, 2009, p. 16).

Cameron concludes that sex differences in linguistic behaviour have been the focus of attention ‘in both academic and popular discourse’ (2009, p.1). However, caution should be urged when following this trend without examining the scientific evidence thoroughly and systematically, as a whole.

Brain plasticity and musical training

This longitudinal study investigated whether musical training improved brain functioning, such as reading and linguistic pitch processing, in ‘nonmusician’ children (Moreno et al, 2008, p. 712).

A total of 37 nonmusician children from two schools in Portugal were enrolled in the experiment for nine months. The children were aged 8 years old. Each child was assigned to to musical training or a control painting group. Event-related brain potentials were recorded while the children performed various tasks.

It was found that ‘musical training improved reading skills and the discrimination of small pitch variations in speech’ (Moreno et al, 2008, p. 716). ‘Improvements in reading abilities as well as enhanced performance in the pitch discrimination tasks that differed between groups, were most likely driven by musical training’(Moreno et al, 2008, p. 718). Training these children with music specifically improved their reading skills in ‘basic auditory analysis, as well as sound segmentation and blending… [and] the development of the phonological representations necessary for reading’ (Moreno et al, 2008, p. 719). These results were not seen in the control painting group.

Musical training also positively affects neural processes in the brain; ‘musical training influences the brain electrical activity associated with the processing of linguistic pitch patterns, and provides evidence for transfer effects from music to speech processing’ (Moreno et al, 2008, p. 721). It was concluded that ‘relatively short periods of training have profound consequences on the anatomical and functional organization of the brain’ (Moreno et al, 2008, p. 721).

‘Remarkably, 6 months of musical training suffices to significantly improve behavior and to influence the development of neural processes, as reflected in the specific pattern of brain waves. These results reveal positive transfers from music to speech and highlight the influence of musical training. Finally, they demonstrate brain plasticity, by showing that relatively short periods of training have strong consequences on the functional organization of children’s brain’ (Moreno et al, 2008, p. 712).

Second-language learning and changes in the brain

Experience and learning ‘can change both the function and the structure of the brain’ (Osterhout et al, 2008, p. 509). In this study, researchers in three separate studies explored how learning a second language directly affects the brain. The subjects in the studies were young adults, but it was noted that the findings are directly translatable to school environments.

Preliminary results indicated that ‘classroom-based, second-language instruction can result in changes in the brain’s electrical activity, in the location of this activity within the brain, and in the structure of the learners’ brains. These changes can occur during the earliest stages of second-language acquisition’ (Osterhout et al, 2008, p. 509).

Specifically, researchers found that:

- Syntactic and semantic anomalies elicit distinct event-related brain potentials. These results suggest that separable syntactic and semantic processes exist in the brain.

- Systematic, measurable structural changes are present in the brains of individuals who have learned multiple languages.

- Structural brain changes resulting from a second language can be observed after a relatively short but intense instructional period, even in a small sample of learners (note that this particular finding came from a study that only used four participants, so the results are not conclusive)

(Osterhout et al, 2008)

The researchers concluded that ‘the brain of an adult second-language learner is a highly dynamic place, even during the earliest stages of second language learning’ (Osterhout et al, 2008, p. 516). These findings also demonstrate brain plasticity, and show that the ‘brain remains remarkably plastic throughout much of life’ (Osterhout et al, 2008, p. 517).